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ABSTRACT

This document is a report on a course in nuclear science for the high school curriculum. The course is designed to provide a basic but comprehensive understanding of the atom in the light of modern knowledge, and to show how people attempt to harness the tremendous energy liberated through fission and fusion reactions. The course crosses what are considered the normal disciplines of science, entering into the three basic fields (biology, chemistry, physics). The document includes sections on laboratory safety and health physics, sources of radioisotope licensing, textbooks and references, equipment, types of students taking the course, an outline of the course of study and its units, laboratory experiments and techniques, and a list of teaching aids. The Appendix contains the United States Nuclear Regulatory Commission Rules and Regulations. (GA)

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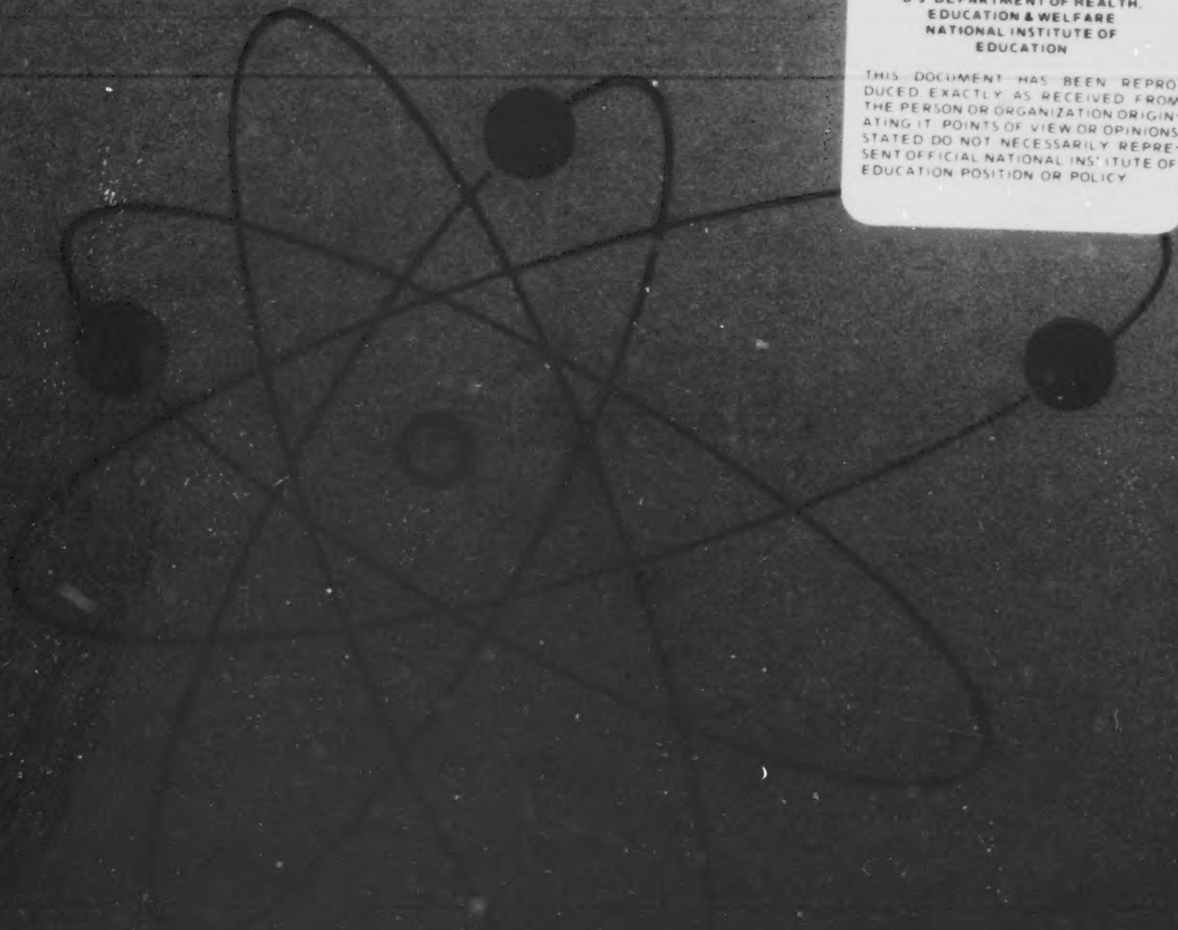

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Nuclear Science

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Milton J. Shapp, *Governor*

Department of Education
Caryl M. Kline, *Secretary*

Office of Basic Education
Frank S. Manchester, *Commissioner*
Harry K. Gerlach, *Deputy Commissioner*

Bureau of Curriculum Services
David C. Campbell, *Director*

Division of Personal Development
Irvin Edgar, *Chief*

Pennsylvania Department of Education
Box 911
Harrisburg, PA 17126

LIST OF CONTRIBUTORS

John J. McDermott, Project Director, Pennsylvania Department of Education
Senior Adviser, Science

Diane McKissick, Penn Hills School District

Robert Boyer, Kane Area School District

John Baughman, Cornwall-Lebanon School District

Stanley Wilhelmson, Rosetree-Media School District

Leslie Ramsey, Indiana Area School District

Vernon Lyter, Lower Dauphin School District

Joseph Sasala, Burrell School District

Paul Shiring, Burrell School District

David Popp, Chestnut Ridge School District

Donald Stoops, West Perry School District

Joanne W. Wood, Central Dauphin School District

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Introduction

This is a report of approximately 13 years of work, thought, and experimentation by many Pennsylvania Nuclear Science teachers concerning the introduction of a course entitled Nuclear Science into the high school curriculum. The course is designed to provide a basic but comprehensive understanding of the atom in the light of modern knowledge. Special attention is paid to the use of the energy of the atom as a contributive factor to modern civilization. This course crosses what are considered the normal disciplines of science, entering into the three basic fields quite freely. It was decided to present this material in a basic fashion, with projections in depth being attempted when deemed advisable by the relative importance of the material, and by class comprehension and interest.

It is hoped that the student will develop an increased understanding of the basic units of matter and energy and in this way attain greater insight into the physical sciences and their relationships with the biological sciences. The concept of the interrelationship of mass and energy will provide a basis for better comprehension of modern physics and chemistry, while the uses of radioisotopes as biological tracers will illustrate their importance in modern research and emphasize the continuity of scientific knowledge and methods from one discipline to another.

This course is designed to develop student awareness of the problems which confront our civilization, such as nuclear disarmament, the health problems of the Atomic Age, and survival in a nuclear war. The course will also show how people attempt to harness the tremendous energy liberated through fission and fusion reactions to provide the energy necessary for the civilization of the future.

I LABORATORY SAFETY

and

HEALTH PHYSICS

With the general lack of knowledge concerning radioisotopes and the unfounded apprehension generated by the word radioactivity, the question of safety will automatically arise with the discussion of initiating a course in which these substances are used. This question was answered quite satisfactorily in a special meeting held by the Board of Education of the City of New York. The conference was attended by the members of the Board, Science Supervisors, Radiologists, Teachers, and representatives of the United States Atomic Energy Commission. The following comments are representative:

> "....No health hazard is involved (to the student or teacher) in carrying out laboratory experiments with radioactive Iodine-131 and Phosphorus-32 in amounts not exceeding ten microcuries."[1]

> "A watch with a luminous dial contains approxiamtely 0.5 microcuries of Radium-226. Therefore, staying for two hours in the vicinity of ten microcuries of Iodine-131, in a closed glass container of sufficient thickness to absorb the beta radiation, (about 2mm) is roughly equivalent to wearing a luminous dial watch for twelve hours. Obviously, the exposure accumulated by the student or teacher in one year would be very much less than that accumulated by a person normally wearing a Radium luminous dial watch."[2]

Questions generally arise concerning the danger of spilling radioactive substances on the skin or clothing. Students should wear a long laboratory coat, rubber gloves, and a rubber laboratory apron when handling unsealed radioactive materials. Then, should a spill occur, the contaminated piece of apparel could easily be removed and laundered to remove the contamination. Even though these precautions are recommended, they are not entirely necessary. A ten microcurie spill of a beta emitter on clothing, disregarding the absorption of the activity by the cloth, would cause a dose rate in the germinal layer of the epidermis approximately equal to six Rads per hour. At this rate, the contaminated clothing would have to remain in close contact with the skin for a period of ten days to one month (a quite unlikely condition) to produce a temporary reddening of the skin resembling sunburn.

> "If a student or teacher drank all the solution containing ten microcuries of Iodine-131 no noticeable harm would result. Even larger amounts are given patients for a thyroid function test. The accidental ingestion of ten microcuries of Phosphorus-32 can also be considered harmless."[3]

It is well to note here that we have been considering only two radioisotopes, Phosphorus-32 and Iodine-131. The above decisions cover all the isotopes available under general Nuclear Regulatory Commission licensing. However, special care should be taken to avoid ingestion or inhalation of alpha emitters, since their high specific ionization may cause more internal cellular damage than a beta emitter which will have a lower specific ionization.

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[1] Board of Education, City of New York, High School Division Report of Meeting to Consider the Safe Handling of Radioisotopes I^{131} and P^{32} in Ten Microcuries Lots, February 6, 1953 revised October, 1958.

[2] Ibid.

[3] Ibid.

> "In this connection, it is well to emphasize the fundamental principle of radiation protection that unnecessary exposure to ionizing radiation should always be avoided. Therefore, care should be exercised to avoid any ingestion or inhalation of radioactive material."[4]

> "That radioactive material be handled with the same care usually afforded corrosive acids is certainly sufficient to insure safety."[5]

Of course, the learning of proper handling techniques with radioisotopes should be part and parcel of the training afforded by the laboratory experiments. Some of the students who are receiving their initial experience with radioactive materials may continue in this field, and bad habits acquired in the handling of small amounts of radioactive substances might be quite difficult to overcome if the need to handle larger amounts should arise later.

In order to insure safety in the laboratory, a definite set of safety rules should be adopted by the instructor. A copy of these rules should be given to the students, and they should be tested concerning them before being allowed to work in the laboratory. Another copy should be prominently posted in the laboratory. Any person who breaks these rules should be seriously reprimanded. All possible precautions must be taken in order to prevent inhalation, ingestion or skin contact with radioisotopes. Therefore, the following rules will be in effect:

1. There will be no eating, drinking or smoking in this laboratory.
2. Keep your hands away from your mouth, nostrils and eyes.
3. All work with unsealed sources must be done in fiberglass work trays. These trays will be lined with paper having a non-absorbent base to retain spills and facilitate decontamination.
4. Laboratory coats must be worn at all times when working in this laboratory.
5. Rubber gloves will be worn at all times when handling unsealed solutions. These gloves must be monitored, washed with detergent and water, remonitored, and rewashed if contaminated before removal. The hands will then be washed and monitored.
6. Signs indicating radioactive materials must be in prominent display during any experiment with unsealed sources.
7. All radioactive contaminated materials must be plainly labeled.
8. Solid radioactive waste will be placed in the plainly marked *hot* waste can. No other type of waste will be placed in this can, and no solid radioactive materials will be disposed of elsewhere.
9. The instructor will be consulted before any radioisotopes may be disposed of, to insure proper disposal.
10. There must be no pipetting by mouth. A propipetter should be used.
11. All spills must be reported immediately, and decontamination procedures initiated under immediate supervision of the instructor.
12. All radioactive sources should be sealed before handling or counting, if practical.

---

[4] Board of Education, City of New York, High School Division Report of Meeting to Consider the Safe Handling of Radioisotopes I^{131} and P^{32} in Ten Microcuries Lots, February 8, 1953 revised October, 1958.

[5] Ibid.

If rules similar to this are inaugurated and enforced, there should be complete safety from contamination in the laboratory, barring human error.

Radioactive contamination of the equipment, furniture, and the laboratory itself must be avoided in order to prevent the contamination of other students, and to prevent raising the background count in the laboratory to the extent that it interferes with the proper functioning of the sensitive Geiger-Muller counters. In order to achieve this, the teacher must be familiar with the general rules of radioisotope safety techniques.

All work with unsealed radioisotopes should be done in nonporous trays of a chemically inert substance, such as fiberglass or heat-resistant plastic. The tray should be lined with paper having a non-absorbent base. Any material spilled on the paper can then be rolled up and properly disposed. Any material spilled on other surfaces should be blotted, the surface scrubbed with detergent and water, dried, monitored, and rescrubbed if necessary to remove the contamination. The scrubbing and monitoring should be continued until no trace of activity above background remains. Of course, the activity of the isotopes used in a high school laboratory is so low that decontamination is a rather simple matter.

> "....Decontamination is considered complete when radioactivity from radioisotope groups I and II is not in excess of one millirep per hour average as measured in a small volume of air above any two square inch area. This corresponds to approximately one thousand counts per minute when a Geiger counter is placed as close as possible to the contaminated area... Note that in many high school experiments the actual counting rate will not greatly exceed that which meets the A.E.C. definition of uncontaminated."[6]

A clearly marked radioactive waste can should be available for the deposition of all contaminated materials. A twenty gallon covered trash can is quite suitable for this purpose. The container should not be emptied with uncontaminated trash, but should be subject to special handling. The paper can be safely incinerated, while the other material can be buried. Another method is to store the can and its contents for a one-year period. At the end of this period, the activity will be reduced by normal radioactive decay. Small animal carcasses contaminated with radioactivity should be placed in glass containers and buried. The containers will prevent the carcasses from being dug up and scattered by foraging animals.

Isotope solutions of the low activity which would be used in the high school laboratory may safely be flushed down the sink. If the tap is allowed to run for five minutes previous to pouring the isotope and twenty minutes after, the activity will be so diluted as to be practically undetectable. It would be well for each individual teacher to contact his/her local health or civil defense authorities concerning this matter.

Any vaporization or sample drying of radioactive material should be done in a hood to prevent the inhalation of radioisotopes.

All laboratory glassware used for radioactive material should be rinsed, washed with detergent, and stored separately from non-contaminated glassware.

The supply of radioisotopes should be stored in a plainly labeled, locked metal container. A metal chest lined with cinder brick has proven to be quite satisfactory for this purpose. The cinder brick acts as a protective shielding, and also gives the box sufficient weight to prevent its being easily moved. Lead bricks may also be used for this purpose.

In order to discourage careless handling, all radioactive contaminated substances should be clearly marked with warning tape.

[6] Miner et. al. **Teaching With Radioisotopes**, U.S.A.E.C. Washington, D.C., 1959

During the laboratory period, one student should be assigned as a laboratory safety officer, whose duty would be the constant monitoring of the laboratory for spills or any other radioactive contamination. He/she should immediately report any spills and aid in decontamination procedures. This will also, by the way, aid in teaching proper safety techniques.

At this point it should be reiterated that radioisotopes used in conjunction with the proper safety precautions are no more dangerous than the corrosive acids which are used as a routine part of every high school chemistry course.

II SOURCES OF RADIOISOTOPES, LICENSING

On June 14, 1946, an article appeared in **Science** announcing that reactor radioisotopes were available from government agencies. On August 2, 1946 the initial shipment, a small amount of Carbon-14, was sent to the Barnard Cancer Hospital in St. Louis, Missouri.

By 1959, the Atomic Energy Commission (presently the U.S. Energy Research and Development Administration) had issued licenses to 2,555 institutions for use in medical application, [illegible]000 to individual companies, and 1,562 to research groups.

> "Figures from Oak Ridge National Laboratory show a rise from 14,162 shipments of a total of 166,629 curies[7] in 1957, to 14,131 shipments of 228,714 curies in the next year, and 12,028 shipments of a total of 222,708 curies in the current year ended November 30, 1959. The shipments do not include those of retail suppliers which approximate 1,000,000 shipments per year."[8]

On January 11, 1956, the Commission made available to the general public small amounts of radioactive materials. Following are excerpts from: *Rules of General Applicability to Licensing of Byproduct Material*, U.S. Nuclear Regulatory Commission Rules and Regulations, Title 10, Chapter 1, Part 30, April 30, 1975.

> **30.18 Exempt quantities.**
>
> (a) Except as provided in paragraphs (c) and (d) of this section, any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 30-34 of this chapter to the extent that such person receives, possesses, uses, transfers, owns, or acquires byproduct material in individual quantities each of which does not exceed the applicable quantity set forth in S30.71, Schedule B.
>
> (b) Any person who possesses byproduct material received or acquired prior to September 25, 1971, under the general license then provided in S 31.4 of this chapter is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 30.34 of this chapter to the extent that such person possesses, uses, transfers, or owns such byproduct material.
>
> (c) This section does not authorize the production, packaging, repackaging, or import of byproduct material for purposes of commercial distribution...
>
> (d) (Refers to restrictions on commercial distribution, import, or transfer of byproduct materials.)
>
> **30.21 General licenses.**
>
> (a) A general license is hereby issued: (2) to transfer, receive, acquire, own, possess, use, and import the quantities of byproduct material listed in 30.71, provided that no person shall at any one time possess or use, pursuant to the general licensing provisions of this paragraph, more than a total of ten such scheduled quantities.

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[7] A curie is the number of radioactive disintegrations equal to that undergone by one gram of radium; *i.e.* 3.7×10^{10} disintegrations $sec.^{-1}$

[8] Radioisotopes in Science and Industry, A Special Report of the Atomic Energy Commission. January, 1960, p. 2.

30.31 Types of licenses.

Licenses for byproduct material are of two types: General and specific. Specific licenses are issued to named persons upon applications filed pursuant to the regulations in this part of Part 32.36. General licenses are effective without the filing of applications with the Commission or the issuance of licensing documents to particular persons.

30.32 Application for specific licenses.

(a) Applications for specific licenses should be filed in duplicate on Form NRC-313. "*Application for Byproduct Material License.*" with the Director of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

30.71 Schedule B.

The following quantities of byproduct material are generally licensed pursuant to 30.21 (a) (2).

Byproduct Material	*Microcuries*	*Byproduct Material*	*Microcuries*
Antimony 122 (Sb 122)	400	Cobalt 58 (Co 58)	10
Antimony 124 (Sb 124)	10	Cobalt 60 (Co 60)	1
Antimony 125 (Sb 125)	10	Copper 64 (Cu 64)	100
Arsenic 73 (As 73)	100	Dysprosium 165 (Dy 165)	10
Arsenic 74 (As 74)	10	Dysprosium 166 (Dy 166)	100
Arsenic 76 (As 76)	10	Erbium 169 (Er 169)	100
Arsenic 77 (As 77)	100	Erbium 171 (Er 171)	100
Barium 131 (Ba 131)	10	Europium 151 9.2h (Eu 152 9.2h)	100
**Barium-133 (Ba 133)	10	Europium 152 13 yr (Eu 152 13 yr)	1
Barium (140 (Ba 140)	10	Europium 154 (Eu 154)	1
Bismuth 210 (Bi 210)	1	Europium 155 (Eu 155)	10
Bromine 82 (Br 82)	10	Fluorine 18 (F 18)	1,000
Cadmium 109 (Cd 109)	10	Gadolinium 153 (Gd 153)	10
Cadmium 115m (Cd 115m)	10	Gadolinium 159 (Gd 159)	100
Cadmium 115 (Cd 115)	100	Gallium 72 (Ga 72)	10
Calcium 45 (Ca 45)	10	Germanium 71 (Ge 71)	100
Calcium 47 (Ca 47)	10	Gold 198 (Au 198)	100
Carbon 14 (C 14)	100	Gold 199 (Au 199)	100
Cerium 141 (Ce 141)	100	Hafnium 181 (Hf 181)	10
Cerium 143 (Ce 143)	100	Holmium 166 (Ho 166)	100
Cerium 144 (Ce 144)	1	Hydrogen 3 (H 3)	1,000
Cesium 131 (Cs 131)	1,000	Indium 113m (In 113m)	100
Cesium 134m (Cs 134m)	100	Indium 114m (In 114m)	10
Cesium 134 (Cs 134)	1	Indium 115m (In 115m)	100
Cesium 135 (Cs 135)	10	Indium 115 (In 115)	10
Cesium 136 (Cs 136)	10	Iodine 125 (I 125)	1
Cesium 137 (Cs 137)	10	Iodine 126 (I 126)	1
Chlorine 36 (Cl 36)	10	Iodine 129 (I 129)	0.1
Chlorine 38 (Cl 38)	10	Iodine 131 (I 131)	1
Chromium 51 (Cr 51)	1,000	Iodine 132 (I 132)	10
Cobalt 58m (Co 58m)	10	Iodine 133 (I 133)	1

Byproduct Material	*Microcuries*
Iodine 134 (I 134)	*10*
Iodine 135 (I 135)	*10*
Iridium 192 (Ir 192)	*10*
Iridium 194 (Ir 194)	*100*
Iron 55 (Fe 55)	*100*
Iron 59 (Fe 59)	*10*
Krypton 85 (Kr 85)	*100*
Krypton 87 (Kr 87)	*10*
Lanthanum 140 (La 140)	*10*
Lutetium 177 (Lu 177)	*100*
Manganese 52 (Mn 52)	*10*
Manganese 54 (Mn 54)	*10*
Manganese 56 (Mn 56)	*10*
Mercury 197m (Hg 197m)	*100*
Mercury 197 (Hg 197)	*100*
Mercury 203 (Hg 203)	*10*
Molybdenum 99 (Mo 99)	*100*
Neodymium 147 (Nd 147)	*100*
Neodymium 149 (Nd 149)	*100*
Nickel 59 (Ni 59)	*100*
Nickel 63 (Ni 63)	*10*
Nickel 65 (Ni 65)	*100*
Niobium 93m (Nb 93m)	*10*
Niobium 95 (Nb 95)	*10*
Niobium 97 (Nb 97)	*10*
Osmium 185 (Os 185)	*10*
Osmium 191m (Os 191m)	*100*
Osmium 191 (Os 191)	*100*
Osmium 193 (Os 193)	*100*
Palladium 103 (Pd 103)	*100*
Palladium 109 (Pd 109)	*100*
Phosphorus 32 (P 32)	*10*
Platinum 191 (Pt 191)	*100*
Platinum 193m (Pt 193m)	*100*
Platinum 193 (Pt 193)	*100*
Platinum 197m (Pt 197m)	*100*
Platinum 197 (Pt 197)	*100*
Polonium 210 (Po 210)	*0.1*
Potassium 42 (K 42)	*10*
Praseodymium 142 (Pr 142)	*100*
Praseodymium 143 (Pr 143)	*100*
Promethium 147 (Pm 147)	*10*
Promethium 149 (Pm 149)	*10*
Rhenium 186 (Re 186)	*100*
Rhenium 188 (Re 188)	*100*
Rhodium 103m (Rh 103m)	*100*
Rhodium 105 (Rh 105)	*100*
Rubidium 86 (Rb 86)	*10*
Rubidium 87 (Rb 87)	*10*
Ruthenium 97 (Ru 97)	*100*
Ruthenium 103 (Ru 103)	*10*
Ruthenium 105 (Ru 105)	*10*
Ruthenium 106 (Ru 106)	*1*

Byproduct Material	*Microcuries*
Samarium 151 (Sm 151)	10
Samarium 153 (Sm 153)	100
Scandium 46 (Sc 46)	10
Scandium 47 (Sc 47)	100
Scandium 48 (Sc 48)	10
Selenium 75 (Se 75)	10
Silicon 32 (Si 31)	100
Silver 105 (Ag 105)	10
Silver 110m (Ag 110m)	1
Silver 111 (Ag 111)	100
Sodium 24 (No 24)	10
Strontium 85 (Sr 85)	10
Strontium 89 (Sr 89)	1
Strontium 90 (Sr 90)	0.1
Strontium 91 (Sr 91)	10
Strontium 92 (Sr 92)	10
Sulphur 35 (S 35)	100
Tantalum 182 (Ta 182)	10
Technetium 96 (Tc 96)	10
Technetium 97m (Tc 97m)	100
Technetium 97 (Tc 97)	100
Technetium 99m (Tc 99m)	100
Technetium 99 (Tc 99)	10
Tellurium 125m (Tc 125m)	10
Tellurium 127m (Te 127m)	10
Tellurium 127 (Te 127)	100
Tellurium 129m (Te 129m)	10
Tellurium 129 (Te 129)	100
Tellurium 131m (Te 131m)	10
Tellurium 132 (Te 132)	10
Terbium 160 (Tb 160)	10
Thallium 200 (Tl 200)	100
Thallium 201 (Tl 201)	100
Thallium 202 (Tl 202)	100
Thallium 204 (Tl 204)	10
Thulium 170 (Tm 170)	10
Thulium 171 (Tm 171)	10
Tin 113 (Sn 113)	10
Tin 125 (Sn 125)	10
Tungsten 181 (W 181)	10
Tungsten 185 (W 185)	10
Tungsten 187 (W 187)	100
Vanadium 48 (V 48)	10
Xenon 131m (Xe 131m)	1,000
Xenon 133 (Xe 133)	100
Xenon 135 (Xe 135)	100
Ytterbium 175 (Yb 175)	100
Yttrium 90 (Y 90)	10
Yttrium 91 (Y 91)	10
Yttrium 92 (Y 92)	100
Yttrium 93 (Y 93)	100
Zinc 65 (Zn 65)	10
Zinc 69m (Zn 69m)	100

Byproduct Material	*Microcuries*
Zinc 69 (Zn 69)	1,000
Zirconium 93 (Zr 93)	10
Zirconium 95 (Zr 95)	10
Zirconium 97 (Zr 97)	10
Any byproduct material not listed above other than alpha emitting byproduct material	

Isotope	**Usual Chemical Form**	**Half-Life**	**Beta Energy (MeV)**	**Gamma Energy (MeV)**
Iodine 131	NaI	8.08 days	0.608 et.	0.364 et.
Phosphorus 32	NaH_2PO_4	14.3 days	1,701	None
Calcium 45	$CaCl_2$	163 days	0.254	None
Carbon 14	Na_2CO_3	5,562 yrs.	0.155	None
Cesium 137	$CsCl$	30 yrs.	0.51 et.	None
Barium 137	$BaCl_2$	2.6 min.	None	0.662
Chlorine 36	KCl	308,000 yrs.	0.714	None
Chromium 51	$CrCl_3$	27.8 days	None	0.32 et
Cobalt 60	$CoCl_2$	5.27 yrs.	0.306	1.17, 1.33
Indium 113m	$InCl_3$	100 min.	None	.393
Iron 59	$FeCl_3$	45.1 days	0.462 et.	0.191, 1098 1.289
Nickel 63	$NiCl_2$	85 yrs.	0.067	None
Ruthenium 106.	$RuCl_3$	1.0.yrs.	0.0392	None
Rhodium 106	$RhCl_3$	30 sec.	3.53 et	0.513, 2.41 et
Sodium 22	$NaCl$	2.6 yrs.	0.58 β^+	0.511, 1.28
Strontium 89	$SrCl_2$	53 days	1.463	None
Strontium 90	$SrCl_2$	25 yrs.	0.61	None
Sulfur 35	H_2SO_4	87.1 days	0.167	None
Thallium 204	$TlNO_3$	4.0 yrs.	0.765	None
Yttrium 90	YCl_3	2.54 days	2.18	None
Zinc 65	$ZnCl_2$	250 days	0.325 β^+	1.12 et

III TEXTBOOKS AND REFERENCES

There is at present no text available which has been written for a course such as this. Rather, a number of references are needed to fill the requirements. The texts which must be used at present are necessarily of college reading level. However, this should pose no problem for the caliber of student enrolled in the course.

Giasstone's **Sourcebook on Atomic Energy** has been used successfully as a general text. A copy of this should be supplied to each student, and the assignments tailored to it. The choice of this text is due to several factors. It is quite complete in its coverage of the general aspects of the field; its presentation is quite readable and understandable on the Senior high school level.

A reference library should be installed in the classroom and the students given free access to it for research and reference work.

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C. Dance, J. B., **Radioisotope Experiments for Schools and Colleges**, 1967, Pergamon Press

D. Hermias & Joecile, **Radioactivity: Fundaments and Experiments**, 1963, New York, Holt, Rinehart & Winston

E. Kamen, Martin D., **Isotopic Tracers in Biology**, 1957, New York, Academic Press

F. Miner, et al., **Teaching With Radioisotopes**, 1959, Washington, U.S. Atomic Energy Commission

G. Nuclear-Chicago Corp., **Radioisotope Experiments for the Chemistry Curriculum**, 1960, Chicago, Nuclear-Chicago Corporation

H. Overman & Clark, **Radioisotope Techniques**, 1960, New York, McGraw-Hill $10.00

I. Overman, Ralph T., **Basic Concepts of Nuclear Chemistry**, 1963, New York, Reinhold

J. Schenberg, Samuel, **Laboratory Experiments with Radioisotopes for High School Science Demonstrations**, 1958, Washington, U.S. Gov't. Printing Office

K. Smullen, W. C., **Basic Foundations of Isotope Technique for Technicians**, 1957, Springfield, Ill, Thomas

L. Steinberg, E. P., **Interpretation of Counting Data**, 1956, Washington, U.S. Department of Commerce

IV. Sources of Bibliographies

A. Special Sources of Information on Isotopes, Washington, D.C., Office of Isotopes Development, U.S.E.R.D.A. Second Revision

V. Free Booklets

Booklets available from **Division of Technical Information, U.S.E.R.D.A.**

1.	**Accelerators**	William J. Kernan
2.	**Plutonium**	William N. Miner
3.	**Atomic Fuel**	John F. Hogerton
4.	**Research Reactors**	Martens & Jacobson
5.	**Controlled Nuclear Fusion**	Samuel Glasstone
6.	**Neutron Activation Analysis**	William R. Corliss
7.	**Power from Radioisotopes**	Robert L. Mead & William R. Corliss
8.	**Synthetic Transuranium Elements**	Earl K. Hyde
9.	**Direct Conversion of Energy**	William R. Corliss
10.	**Food Preservation by Irradiation**	Grace M. Urrows
11.	**Microstructure of Matter**	Clifford E. Swartz
12.	**Careers in Atomic Energy**	Loyce J. McIlhenny

IV EQUIPMENT

Equipment for the Nuclear Science course, due to its nature, is expensive. The following list represents the minimal requirements for the installation of a usable laboratory for student use. Additional items may be added at the discretion of the instructor, according to available funds.

FOR EACH LAB STATION

A. Recommended:

- Scaler with timer
- End Window Geiger-Muller tube with mount and cable
- Absorber Set
- α, β, and γ Sealed Source Set (Po-210, Sr-90, Co-60)
- Cs-137 Sealed Source
- Fiberglass isotope work tray (Cafeteria type)
- Cs-137/Ba-137m Minigenerator
- Planchets
- Planchet Tricepts
- Propipetter
- Assorted Micropipettes

B. Optional:

- Side-window Geiger-Muller tube with mount and cable
- Split Source Set
- Calibrated Source Set
- Calculator

CLASSROOM EQUIPMENT

A. Recommended:

- Wilson Cloud Chamber
- Solid Waste Container
- Isotope Storage Container
- Survey Meter (CDV-700)*
- Dosimeter and Charger*

B. Optional:

- Ratemeter
- Scintillation Detector
- Gamma Ray Spectrometer
- Chart Recorder
- Air Sampler
- Radiochromatography Scanner

*Civil Defense equipment recommended

GENERAL SUPPLIES:

Disposable Plastic Gloves
Plastic Food Wrap
Small Plastic Bags
Aluminum Foil
Protective Absorbent Paper for Work Trays
X-ray film and appropriate developing materials or Polaroid Film Packs
Warning Signs, Tape, and Tags
Warning Rope
2 Spare Geiger-Muller Tubes
Liquid Sources
Isotope Coupons
Assorted Glassware including small sizes

SOURCES OR EQUIPMENT

The following concerns supply equipment and may be contacted for their current catalogues:

1. Educational Materials & Equipment Co.
   Box 63
   Bronxville, N.Y. 10708

2. Atomic Accessories, Inc.
   811 West Merrick Road
   Valley Stream, N.Y. 11582

3. Central Scientific Co.
   1700 Irving Park Road
   Chicago, Ill. 60613

4. Welch Scientific Co.
   7300 N. Linder Avenue
   Skokie, Ill. 60076

5. The Nucleus
   P. O. Box R
   Oak Ridge, Tenn. 37830

An excellent source of specimen irradiation available to all teachers is the radiological laboratory of the local hospital. If the situation is explained in detail to the Radiologist in charge, it is possible that he/she will make his/her X-ray and gamma-ray equipment available for this purpose. Excellent studies of the effect of radiation on seed germination and the production of mutations, to list just two, may be made with this equipment. This is also a possible source of isotopes and X-ray film.

V TYPE OF STUDENTS

This course should be intended primarily as an enrichment program and is not recommended for students of low ability or achievement. The subject matter is rigorous in comparison with the average high school course but the pace and depth of subject matter covered may be altered to fit the needs of the students enrolled.

The students in this course should have completed biology and either chemistry or physics to insure sufficient background in scientific theory and laboratory techniques. They should also have completed a course in algebra to enable them to correctly manipulate the equations and other necessary mathematical computations involved in this program. Some math instruction, such as the use of natural logarithims, may be necessary. The use of calculators will aid the student tremendously in quickly and efficiently solving complex problems.

This course should not be intended to replace physics or chemistry. One of these subjects should be taken simultaneously. Indeed, a course such as this should serve to bring about increased understanding of these subjects, rather than replace one of them.

The reading ability of the student should be of a superior nature, as the textbooks available at the present time are of college reading level. This, of course, may change in the future.

VI A COURSE OF STUDY FOR NUCLEAR SCIENCE

GENERAL OVERVIEW - The subject matter in this course cuts across the various scientific disciplines; consequently, it helps students tie together the various science courses they have taken. Radioisotopes are used as tracers in physical, chemical, and biological experiments. The course includes historical development of the atomic concept, atomic particles, electromagnetic radiations, the dualistic nature of radiant energy, some concepts of quantum theory, Compton scattering, the photoelectric effect, and radioactivity.

	Unit	Suggested Time One Semester Program	Full Year Program
I	Introduction: Atomic Energy	2 weeks	3 weeks
II	Atomic Particles and Electromagnetic Radiations	2 weeks	3 weeks
III	The Dualistic Nature of Radiant Energy	2 weeks	5 weeks
IV	The Structure of the Atom	3 weeks	5 weeks
V	Radioactivity	2 weeks	4 weeks
VI	Measurement of Nuclear Radiations	1 week	2 weeks
VII	Particle Accelerators	1 week	2 weeks
VIII	Nuclear Fission	1 1/2 weeks	3 weeks
IX	Nuclear Fusion	1 week	2 weeks
X	Radiation Health Physics	1 1/2 weeks	3 weeks
IX	Radioisotope Applications	1 week	1 1/2 weeks
	TOTAL Time	18 weeks	33 1/2 weeks

UNIT I

INTRODUCTION: Atomic Energy

Suggested Time: 3 weeks

OVERVIEW - The early Greek Atomists held the view that all matter was composed of small invisible particles or *atoma*. This view was replaced by the theories of Aristotle which held sway for nearly 2,000 years until eliminated by the experimental and theoretical work of men such as Lavoisier, who gave us workable hypotheses from which our modern theories have evolved. A general comprehension of these early theories and how and why they have been replaced is perhaps the best way to understand the evolution of our present theories and to realize that these, far from being complete, are in constant revision in the light of new experimental knowledge.

OBJECTIVES

1. The class shall apply the historical evolution of the atomic theory as a prime example of science, using processes of induction and deduction from accrued data presented in the Nuclear Science Course to construct models that are subject to constant revision in the light of new experimental data.

   1.1 The student shall differentiate between inductive and deductive reasoning by identifying specific examples of each reasoning type from the material presented in the classroom.

   1.2 The student shall delineate graphically the Aristotelian view of matter and explain why it was no longer tenable following the work of Priestly and Lavoisier.

   1.3 The students shall explain the atomic concept as first proposed by Dalton. They will indicate the modern modifications of the original theory, supplying the experimental reasons for these modifications.

   1.4 The students shall construct, in historical sequence, the Daltonian, Thompsonian, and Rutherfordian models of the atom. They will list Bohr's modifications of the Rutherford atom and, finally, construct the probability cloud model.

   1.5 The student shall, in a test situation, correlate the symbol of each element with its accepted name from a list of all presently known elements. Eighty-five identifications from the total number of known elements shall be the lowest acceptable limit of performance.

   1.6 Given the periodic chart of the nuclides, the student shall identify the atomic weight, atomic number, electron shell configurations, number of neutrons, and common valence of atoms of elements chosen by the teacher.

      1.6.1 Given a chart of the nuclides, the student shall identify the isotopes, isobars, isotones and nuclear isomers of elements selected by the teacher.

      1.6.1.1 From the above mentioned chart, the student shall identify the type and energy of the nuclear emissions of radioisotopes selected by the teacher. The student shall also identify the daughter nuclide produced by the emission of that particle and construct a balanced nuclear equation for the reaction.

   1.7 The student shall construct chemical formulas from a list of elements with their valences. The student shall then calculate the molecular weights of these compounds. Utilizing the Avogadro number, they shall calculate the weight of a single molecule of a preselected compound.

   1.8 Through laboratory activities the student shall become proficient in the operation of radiation counting equipment and the quality control procedures for such instrumentation.

CONTENT

I. The methods of science

   A. Inductive and deductive reasoning
   B. Microphysics and macrophysics

II. The atomic concept

A. Historical background

1. The early Greek Atomists
2. The Four Element Theory
3. Lavoisier and the death of the Aristotelian view
4. Dalton's Atomic Theory
5. The nuclear atom
6. Modern modifications of these theories

B. The chemical elements

1. Symbols
2. Atomic number
3. Atomic weight
4. Isotopes, isobars, isotones, nuclear isomers

C. Atoms and molecules

1. Compounds
2. The Molecular Concept
3. Molecular weights: The Mole
4. Molecular sizes
5. The Avogadro Number

D. Basic Laboratory Techniques and Instrumentation

1. Laboratory Safety Procedures
2. Operation of Geiger-Muller Counters
3. Statistics of Geiger-Muller Counting
4. Efficiency of Geiger-Muller Counting

SUGGESTED ACTIVITIES

Student Experiments

1. Scientific observation and description (Observations on a Candle: CHEM Study)
2. The Black Box: The methods of science (Chemical Bond Approach)
3. Determination of the operating voltage of the Geiger-Muller tube
4. Statistics of counting
5. The efficiency of a geiger counter
6. Determination of the Avogadro Number

Teacher Demonstrations – Discussions

In this unit the following are recommended:

1. The electromagnetic spectrum
2. Electron energy levels of the Bohr atom as indicated by emission spectra of substances energized with ultra-violet light.
3. The correct operating procedures for the radiological instruments used in the course
4. Shielding from nuclear radiations; safety techniques.

Films

1. *A is for Atom,* 15 minutes
2. *Living with Radiation,* 45 minutes
3. *Fundamentals of Radioactivity,* 30 minutes
4. *Atomic Physics,* 90 minutes
5. *Controlling Atomic Energy,* 13 1/2 minutes
6. *A Sea We Cannot Sense,* 27 1/2 minutes
7. *Introducing Atoms and Nuclear Energy,* 11 minutes
8. *The Mass of Atoms,* 47 minutes

Suggested study guide questions for each unit will be found in Chapter VII.

UNIT II

ATOMIC PARTICLES AND ELECTROMAGNETIC RADIATIONS

Suggested Time: 3 weeks

OVERVIEW - This unit describes the basic subatomic particles which constitute the atoms of matter and their relationships with each other.

OBJECTIVES

1. The student shall construct and demonstrate, in the manner requested by the teacher, theoretical models of atomic and subatomic structures from the material and data provided by the teacher, resource books, text, and experimental investigations in this unit.

    1.1 The student shall differentiate between static and dynamic electricity from demonstrations and experimentation in the classroom. The student shall show this difference in the manner requested by the teacher.

        1.1.1 The student shall indicate comprehension of the units of measurement of electricity by utilizing these units to solve general problem types. (*Units* means volt, ampere, ohm, coulomb, and watt. *Problem types* means specific mathematical relationships between these units, and conversions from one unit to another.)

    1.2 The student shall construct graphically a model of the cathode ray tube. The student shall state the properties of cathode rays (mass, charge, path in the tube), and shall state experimental evidence presented by classroom demonstrations to support the statements of properties.

    1.3 The student shall describe in a manner prescribed by the teacher the properties of the electron. (*Properties* means mass, charge, particle radius, and half life.)

    1.4 The student shall describe from the material presented in the course the production, absorption, wavelengths, and general nature of X-rays.

    1.5 The student shall, in a test situation, name the properties of the neutron, proton, alpha particle, beta particle, deuteron, neutrino, pi, mu, and K mesons, triton, and cosmic rays. (Please refer to 1.3 for the definition of properties.) The correct identification of nine from a list of eleven shall be the lowest acceptable standard of performance.

1.5.1 For each of the above particles, the student shall identify by graphic means its matching antiparticle. The student shall, by utilizing the Einstein mass-energy equation, calculate mathematically the energy produced by the mutual annihilation process – the collision of each particle with its antiparticle.

1.5.2 Given the mass in grams of one atomic mass unit, the student shall calculate mathematically its energy equivalence by utilizing the mass-energy relationship. The student shall then convert this into MeV.

1.6 The student shall construct graphically nuclear equations for the bombardment of nuclei by particles and for the transmutations occurring from radioactive emanations.

CONTENT

I. The fundamental nature of electricity

   A. Static and dynamic electricity
   B. Units of measurement
   C. Current flow
   D. Development of Vacuum tubes
   E. Cathode rays and the Edison Effect

II. The fundamental particles: Leptons, Hyperons, and Baryons

   A. Electron
   B. Proton
   C. Neutron
   D. Positron
   E. Antiproton
   F. The Mesons
   G. Alpha particles
   H. Neutrinos
   I. X and Gamma radiation
   J. Cosmic rays and strange particles
   K. Antiparticles

III. Matter - antimatter interactions

   A. Annihilation radiation
   B. Mass-energy relationship
   C. Energy equivalent of one atomic mass unit
   D. Mass - energy interconversions

SUGGESTED ACTIVITIES

Student Experiments

1. Calculation of dead time or resolving time of a G-M tube
2. Particle tracks in the Wilson Cloud Chamber
3. Cosmic rays
4. Indestructability of radioactivity
5. Magnetic deflection of beta particles

Teacher Demonstrations

1. Determination of the e/m of the electron
2. The van de Graaf Electrostatic Generator
3. Static electricity; attraction and repulsion
4. The Cathode Ray Tube
5. Magnetic deflection of cathode rays

Films

1. *The Radioisotope: Methodology*, 45 minutes
2. *Alpha, Beta, and Gamma-Radioactive Particles*, 44 minutes
3. *Nuclear Reactions*, 17 1/2 minutes
   (Lecture)

UNIT III

THE DUALISTIC NATURE OF RADIANT ENERGY

Suggested Time: 5 weeks

OVERVIEW - This unit introduces the student to the Newtonian or corpuscular theory concerning the nature of radiant energy, and to the electromagnetic theory of these radiations. The dilemma of supporting proof for both theories is alleviated by the dualistic explanation. A study of basic Quantum Mechanics leads the student to the relativistic concepts of Lorentz and Einstein, and the general and special theories of relativity are explored.

OBJECTIVES

1. The student shall apply (by explaining specific cases supplied by the teacher) the dualistic explanation of radiant energy to resolve the apparent contradictions shown by the Newtonian or corpuscular and the electromagnetic theories of light.

   1.1 The student shall construct a model of the electromagnetic spectrum from the materials presented by the teacher, the text, laboratory investigations, and audio-visual materials. The student shall differentiate between the accepted areas of the spectrum from radio waves to cosmic rays.

      1.1.1 The student shall show the mathematical relationships between the energy, frequency, and wavelength of an electromagnetic wave by solving teacher-constructed problems. Eight correct solutions from a total of ten presented shall be the minimum acceptable level of performance.

      1.1.2 Given the index of refraction, the student shall calculate the velocity of light traveling through various transparent media.

   1.2 The student shall describe the model of an ideal *black body* from material presented in the class.

   1.3 From material presented in the class, the student shall explain the current theories of light emission by atoms. The student shall explain the production of emission and absorption spectra, utilizing the material described above.

1.4 The student shall theorize as the teacher requests to explain Laue patterns produced by crystals (acting as diffraction gratings) as acceptable indications of the wave nature of electromagnetic radiations and of subatomic particles approaching the velocity of light.

1.5 Utilizing the Heisenberg uncertainty principle, the student shall correctly determine the uncertainty in position or velocity of electrons in specific problematical cases presented by the teacher.

2. The student shall utilize mathematically the relativistic concepts of Lorentz and Einstein to calculate mass increase, time dilation, length decrease, and energy transformations occurring to subatomic particles approaching the velocity of light.

2.1 Utilizing the Lorentz relativistic equations, as presented by the class, reference works, and the teacher, the student shall show by means of mathematical calculations the changes in mass, length, time, momentum, and energy occurring to any body approaching the velocity of light.

2.1.1 From these equations the student shall explain orally and graphically why the velocity of light is postulated to be the ultimate speed in the universe.

2.2 Given the Einstein mass-energy relationship and Planck's equations, the student shall explain, in a manner chosen by the teacher, the unified theory of the relationship of mass and energy.

2.3 The student, utilizing the material presented in this unit, shall show the theoretical reasons why particles are accelerated to extremely high velocities for nuclear bombardment.

2.4 Using the Lorentz equations as background material, the student shall explain, in a test situation, the Special Theory of Relativity, as required to do so by the teacher.

CONTENT

I Waves

A. The Quantum Theory
B. Planck's Constant
C. Diffraction of waves
D. Heisenberg: The Principle of Uncertainty
E. The significance of wave properties

II. Particulate characteristics of radiations

A. The photon
B. Compton scattering
C. The photoelectric effect

III. Wave - particle duality

IV. Relativistic relationships

   A. The velocity of light
   B. The Lorentz Equations
   C. The general and special theories of relativity
   D. The Conservation of Mass-energy

SUGGESTED ACTIVITIES

Student Experiments

1. Waves on a coil spring
2. Experiments with the ripple tank
3. Wave diffraction
4. Photoelectric effect
5. Determination of Planck's Constant using Light Emitting Diodes.

Teacher Demonstrations - Discussions

1. Models of changes in the mass and length of an arrow as it approaches the velocity of light (graded lengths.) Calculate length and mass changes utilizing the Lorentz Transformations.

Lecture - Discussions

1. Newtonian and wave theories of light
2. The Quantum Theory
3. The deBroglie Equations
4. Compton scattering
5. Conflicts between Quantum physics and Newtonian physics
6. Defense of Newtonian physics

Film

1. *Radiation and Matter,* 44 minutes

UNIT IV

THE STRUCTURE OF THE ATOM

Suggested Time: 5 weeks

OVERVIEW - Dalton considered the atom to be an infinitely small, indivisible, solid particle. Later theories pictured it to consist of opposing charges located upon the surface of a solid sphere. With Rutherford's theory of the nuclear atom, experimental investigations led to the modern concepts of the nature of the atom and to the understanding of subatomic structures and forces.

OBJECTIVES

1. The student shall apply nuclear theory as presented by the resource materials to construct, as required by the teacher, currently acceptable models of the atomic nucleus. The student shall indicate lapses in our present knowledge that will probably lead to alterations of these models.

   1.1 The student shall repeat Objective 1.4, (Unit I), including the refinements presented in this unit.

1.1.1 The student shall construct nuclear models of atoms selected by the teacher. The student shall include in this model the nuclear radius, the neutron-proton ratio, the binding energy, the packing fraction, and the nuclear volume.

1.2 The student shall define orally and graphically the concepts of isotopes, isobars, isomers, and isotones by indicating the mass numbers and atomic numbers of the respective nuclides.

1.3 The student shall utilize the concept of binding energy produced by the mass defect to explain, theoretically, differences which occur in nuclear stability.

1.4 Utilizing the concept of nuclear isomerism, the student shall explain why particles with varying energies are emitted from the nucleus. The student shall use these concepts to explain gamma emission.

1.5 Given the nuclear spin quantum numbers, the student shall demonstrate in a mathematical manner that nuclear spin is the resultant of the individual spins of the nucleons.

1.6 The student shall construct, in the accepted manner, energy level diagrams for nuclear reactions.

1.7 The student shall construct an energy level model of the nucleus from the information presented by the text, the teacher, and resource materials concerning isomeric transition, periodicity in packing fractions and binding energies, the *magic number nuclei,* evidence of neutron-proton pairing, and gamma emission.

1.8 Given a nuclear reaction and the masses of all particles involved, the student shall calculate the energy of that reaction.

CONTENT

I. Early theories

   A. Dalton
   B. Thompson

II. Rutherford and the nuclear atom

   A. The nucleus

      1. Nuclear particles
      2. Nuclear binding energy
      3. Nuclear mass and size
      4. Changes within the nucleus
         a. A and Z numbers
         b. Nuclear emissions
         c. Transmutations
         d. Isotopes, isobars, isotones, nuclear isomers
      5. Nuclear charge
         a. Nuclear energy levels
         b. Gamma radiation

   B. Orbital electrons

30

1. Charge and mass
2. Electron orbitals
3. X-ray Spectra

III. The probability concept of the atom

SUGGESTED ACTIVITIES

Student Experiments

1. Beta particle shielding
2. Gamma ray shielding
3. Determination of half-thicknesses of absorbers
4. Decontamination procedures

Films

1. *The Alchemist's Dream* (transmutations), 29 minutes
2. *Handle With Care: The Safe Handling of Radioisotopes*, 21 1/2 minutes (see Chapter I)

UNIT V

RADIOACTIVITY

Suggested Time: 4 weeks

OVERVIEW - This unit develops the basic principles governing the emission and absorption of nuclear radiations and the effects of these emissions and absorptions upon matter through which they pass.

OBJECTIVES

1. The student shall demonstrate the principles of radioactive decay by explaining (by means of graphic and verbal tests) the mechanics of alpha, beta, positron, and gamma emission, the random nature of radionuclide disintegration, the formation of decay chains, and the concept of half-life.

   1.1 The student shall relate, as required by the teacher, the historical background of the discovery of radioactivity by Becquerel and Curie.

   1.2 The student shall identify the naturally occurring types of emitted particles as to mass, charge, and energy ranges.

   1.3 The student shall describe (by means of nuclear equations) one of the four natural radionuclide decay chains, showing all parent and daughter nuclides.

   1.4 The student shall construct, on semilogarithmic graph paper, a graph of counts-per-minute of a radioactive sample of short, half-life sample, taken daily over several half-lives, plotted against time. From this graph the student shall calculate the half-life of the element and its decay constant.

      1.4.1 Using two counts from the above data, the student shall determine algebraically the decay constant and half-live of the radioactive sample.

      1.4.2 Given any two counts from the same sample separated by a suitable time interval, the student shall calculate the decay constant and half-life of the sample.

1.5 From the material presented in class, the student shall construct a graph and utilize it to explain radioactive equilibrium.

1.6 Given any equation representing radioactive decay, the student shall construct an energy level decay scheme for that particular reaction (See Objective 1.6 of Unit IV.)

1.7 Given the half-life of any radionuclide, the student shall calculate the mean life for any atom of that radionuclide.

1.8 The student shall explain, in the manner requested by the teacher, the separation of radioactive decay products, the use of carriers for radioisotopes, and the recoil method of radionuclide separation.

1.9 The student shall supply examples of the utilization of radioisotopes as *normal type tracers* in biological and chemical systems.

CONTENT

I. The nature of radioactive emanations

   A. Alpha particles
   B. Beta particles and positrons
   C. Electromagnetic radiations

II. Naturally radioactive elements

III. Artificially induced radioactivity

IV. Induced and spontaneous transmutations

V. Radioisotopes - radionuclide production

VI. Radioactive decay

   A. Decay as a random process
   B. Natural and artificial disintegration series
   C. Half-life
   D. Daughter nuclides

SUGGESTED ACTIVITIES

Student Experiments

1. Determination of half-life of a short-lived radionuclide.
2. The construction of half-life curves and calculations of decay constants for various radioisotopes.
3. Separation of radioactive compounds by paper chromatography and chromatogram scanning
4. Background radiation: air sampling

Films

1. *The Art of Separation*, 29 minutes
2. *Properties of Radiation*, 30 minutes

32

3. *Invisible Bullets*, 29 minutes
4. *Man and Radiation*, 28 1/2 minutes

UNIT VI

MEASUREMENT OF NUCLEAR RADIATIONS

Suggested Time: 2 weeks

OVERVIEW - This unit familiarizes the student with the various devices in present use to detect nuclear radiations.

OBJECTIVES

1. The student shall show by demonstration, oral explanation, and graphic means the utilization of various devices designed to detect and record the presence of ionizing radiations.

   1.1 The student shall explain, in the manner required, that all radiations lose their energy by causing ionizations within the material through which they pass.

      1.1.1 Given the fact that an ionizing event requires an average energy of thirty-four electron volts, the student shall calculate the total ionization of any radiation for which he/she is given the energy.

      1.1.2 The student shall relate the specific ionization (number of ion-pairs per unit of track length) to the charge and velocity of the radioactive particle. The student shall contrast this with the total ionization of the particle.

         1.1.2.1 From the above material, the student shall name in order the most damaging radiations to a biological system from internally and externally deposited radionuclides.

   1.2 From the classroom material concerning the loss of energy of a radioactive particle by ionization, the student shall explain, in a test situation, the absorption of beta particles producing *bremsstrahlung ("braking radiation")*.

   1.3 The student shall explain in a written and oral manner the theory and operation of the ionization chamber. The student shall differentiate between integrating and nonintegrating instruments and discuss the uses of scalers.

   1.4 Presented with a Geiger-Muller tube having the end window removed, the student shall identify the parts by naming them orally, and shall explain in a written test the theory of operation of the tube, including the type of gas within the tube, the concept of the Townsend avalanche, the need for and the mechanics of quenching, the gas amplification factor, and the resolving time.

   1.5 The student shall reconstruct graphically the idealized graph of counts per minute versus applied voltage of a Geiger-Muller tube. Areas of the graph that he/she will identify are the starting voltage, threshold of the plateau, the Geiger-Muller plateau, and the area of continuous discharge. The student will then select the optimal operating voltage for the tube.

   1.6 From the material presented by the text, the teacher, and resource materials, the student shall, in a test situation, present the theory of radiation detectors which operate on the principle of phosphor scintillation produced by incident radiations. (*Radiation detectors* means: the spinthariscope and scintillation spectrometer.)

1.7 The student shall indicate a working knowledge of the Wilson cloud chamber by setting up, operating, and explaining the tracks produced in the chamber.

CONTENT

I. Ionization counters (chambers)

II. Proportional counters

III. Geiger-Muller Counters

IV. Scintillation counters

  A. Spinthariscope
  B. Scintillation spectrometers

V. Cloud chambers and bubble chambers

VI. Photographic emulsions

SUGGESTED ACTIVITIES

Student Experiments

1. The Dosimeter
2. Autoradiography
3. The Spinthariscope (Optional)
4. The Lauritzen Electroscope (Optional)

Teacher Demonstrations and Lectures

1. Theory of the Proportional Counter
2. Autoradiographic techniques

Films

1. *An Added Sense: The Detection of Nuclear Radiation*, 24 minutes
2. *Combustion Techniques in Liquid Scintillation Counting*, 25 minutes
3. *Radiation Detection by Ionization*, 30 minutes
4. *Radiation Detection by Scintillation*, 30 minutes
5. *The Scintillation Camera*, 10 minutes

UNIT VII

PARTICLE ACCELERATORS

Suggested Time: 2 weeks

OVERVIEW - This unit is designed to acquaint the student with the various types of accelerators, their construction, and the specific particles for which they can be employed.

34

OBJECTIVES

1. The student shall explain orally and mathematically the operation of accelerating devices designed to penetrate the nuclear coulombic barrier to positively charged ions, and explain, in the manner required by the teacher, the nuclear mechanisms by which transmutations occur.

   1.1 The student shall present, in writing, theoretical explanations of the mechanisms of teacher-selected examples of artificially induced nuclear transmutations, including the primary nuclide, the impinging particle, the products, and the energy requirements of the reaction. The student shall include all mass and charge numbers in the equations.

   1.2 The student shall construct models (as required by the teacher) of the Cockroft-Walton voltage multiplier and the Van de Graaff electrostatic generator. The student shall explain the mechanics of the voltage buildup, discharge and ion acceleration.

   1.3 Given a schematic diagram of the drift-tube type of linear accelerator, the student shall identify and indicate the functional mechanisms of the graduated length drift tubes, the R-F oscillator, and the ion source.

   1.4 Given a schematic diagram of the cyclotron, the student shall identify and indicate the function of the dees, electromagnet, and R-F oscillator. The student shall identify the relative positions of the electric and magnetic fields and explain theoretically the function of the eddy currents which carry the ions, and the method of acceleration of these ions.

      1.4.1 The student shall describe mathematically the motion of ions within the cyclotron. The student shall predict by calculations the radius, angular momentum, and energy of a specific ion under conditions selected by the teacher.

   1.5 The student shall describe graphically and mathematically the betatron when given a schematic diagram of that device. The student shall identify the components and their functions.

CONTENT

I. Voltage multipliers

II. Van de Graaff Electrostatic Generators

III. Cyclotron

IV. Betatron

V. Linear accelerators

SUGGESTED ACTIVITIES

Student Experiments

1. The Discharge tube
2. Particle collisions. (Use billiard balls or ball bearings)

Teacher Demonstration and Discussion

1. The Van de Graaff Electrostatic Generator
2. Deflection of electrons in a cathode ray tube
3. Eddy currents in the model cyclotron
4. Model mass spectrometers
5. The relationship of particle mass to its deflection in a magnetic field. (Use steel ball bearings on inclined plane, and a large permanent magnet.)

Films

1. *Atom Smashers,* 18 minutes
2. *A Beginning Without End,* 30 minutes
3. *Building an Atomic Accelerator,* 28 minutes
4. *Exploring the Atomic Nucleus,* 13 1/2 minutes
5. *Fabrication of the Accelerator Structure,* 40 minutes
6. *Searching for the Ultimate,* 29 minutes
7. *Synchrotron,* 14 1/2 minutes
8. *The Worlds Within,* 29 minutes
9. *A Journal of Plutonium,* 47 minutes
10. *Link,* 8 minutes
11. *Microscope for the Unknown,* 29 minutes
12. *Of Man and Matter,* 29 minutes

Field Trips

Field trips to nearby educational and research accelerators should be attempted if possible.

UNIT VIII

NUCLEAR FISSION

Suggested Time: 3 weeks

OVERVIEW - This unit explains in depth the mechanics of nuclear fission and the requirements which must be met to achieve a sustained chain reaction.

OBJECTIVES

1. The student shall apply nuclear theory as presented by the teacher, the text, and resource materials to construct models of the mechanics of fission and the sustained chain reaction. The student shall demonstrate, verbally and graphically, utilizing drawings and models, the construction of nuclear reactors.

    1.1 The student shall write the generalized nuclear equation for the fission process. The student shall include the mass and charge numbers and indicate the average number of neutrons produced and the average energy in megavolts per fission.

    1.2 Given a specific nuclear fission equation and the masses of all reactants and products, the student shall calculate mathematically the mass loss and the energy release.

    1.3 Given a semilogarithmic chart of the nuclei formed in fission, the student shall, in the manner required by the teacher, identify the mass number of the nuclides most frequently formed. From this chart the student shall show the graphic methods of computing the mass distribution of products.

1.4 The student shall, in a test situation, differentiate between prompt and delayed neutrons resulting from fission.

1.5 Utilizing the liquid drop nuclear model as presented in the class, the student shall graphically illustrate the concept that fission is caused by the captured neutron supplying sufficient energy to deform the nucleus to the state where electrostatic repulsion overcomes the binding force.

1.6 The student shall, from the materials supplied by the teacher, the text and resource materials, illustrate graphically the concept of the chain reaction occurring when sufficient nuclei are present to assure probability of the capture of polyergic neutrons produced by fission (critical mass).

1.7 From the materials presented in the class, the student shall define, in a test situation, the following items: fast neutron fission, slow neutron fission, fissile isotopes, neutron moderators, critical mass, critical density, and multiplication factor. The lowest limit of acceptable performance is seventy per cent correct identification.

1.8 Given a schematic diagram of a typical swimming-pool-type nuclear reactor, the student shall identify and note the function of the fuel charge, pool, control rods, biological shield, neutron reflector, irradiation blocks, and heat exchanger.

1.9 The student shall list the similarities and differences between the nuclear reactor and the fission bomb. A list of ten similarities and differences shall be the lowest acceptable limit of performance.

1.9.1 The student shall construct models of and explain the differences between the critical mass or gun barrel bomb and the critical density or implosion bomb.

1.9.2 The student shall, on a teacher-prepared test, identify the fast neutron fissibility of the bomb, its energy release in kiloton equivalents, the temperature of the fireball, and the blast characteristics. The student shall illustrate fallout patterns dependent upon the blast altitude and indicate the method of the production of radioactive debris by the formation of fission products.

CONTENT

I. The concept of fission

A. Fissile isotopes
B. Energy release
C. The mechanics of fission

1. The chain reaction
2. Critical mass and density
3. Fission products
4. The liquid drop nucleus

II. The fission bomb

  A. History
  B. Types

    1. Critical mass (gun barrel) bomb
    2. Implosion (critical density) bomb

III. Controlled chain reactions

  A. The nuclear reactor

    1. Fissile isotopes as fuel
    2. Neutron source to sustain criticality
    3. Moderators and control rods
    4. Coolants
    5. Biological shielding

  B. Reactor types

    1. Graphite moderated
      a. boiling water
      b. pressurized water
    2. Swimming pool reactors

  C. Reactor uses

    1. Power
    2. Isotope production
    3. As a high level source of neutrons and gamma rays

SUGGESTED ACTIVITIES

Student Experiments

This unit, as the last, does not lend itself to correlated student experiments. However, the use of well-selected films is designed to fill this void. The following experiments are designed to further familiarize the students with radiological methodology.

1. Electroscopes
2. Identification of radiations emitted by a source
3. Shielding of alpha particles

Teacher Demonstrations

1. The Chain Reaction (Demonstrated with mousetraps attached with threads.)

Films

1. *Research Reactors, U.S.A.*, 45 minutes
2. *EBR-I Core Assembly After Meltdown*, 30 minutes
3. *Reactor Fuel Processing*, 30 minutes
4. *Advanced Test Reactor*, 9 minutes
5. *Atomic Furnaces*, 29 minutes
6. *Atomic Power Production*, 14 minutes

7. *Basic Principles of Power Reactors,* 8 1/2 minutes
8. *A Breeder in the Desert,* 29 minutes
9. *Development and Fabrication of HFIR Target Elements,* 14 1/2 minutes
10. *Current methods in Plutonium Fuel Fabrication,* 30 minutes
11. *The Day Tomorrow Began,* 30 minutes
12. *In Search of a Critical Moment,* 28 minutes
13. *Principles of Thermal, Fast, and Breeder Reactors,* 9 minutes
14. *The First Twenty-Five Years,* 28 minutes
15. *The Fuel of the Future,* 27 minutes
16. *Reactor Safety Research,* 15 minutes
17. *The Safe Handling of Enriched Uranium,* 22 minutes
18. *Safety - Second to None,* 14 1/2 minutes
19. *The SL 1 Accident-Phases 1 and 2,* 40 minutes
20. *The SL 2 Accident - Phase 3,* 57 minutes
21. *SRE Core Recovery Following Fuel Element Damage*
22. *In Search of a Critical Moment,* 28 minutes
23. *Inside the Yankee Core,* 32 minutes
24. *Landmark,* 13 1/2 minutes
25. *Molten Salt Reactor Experiment,* 20 minutes
26. *Nuclear Power and the Environment,* 14 minutes
27. *Nuclear Power in the United States,* 28 minutes
28. *Oak Ridge Research Reactor,* 20 minutes
29. *The Petrified River,* 28 minutes
30. *The Transuranium Elements,* 58 minutes
31. *Transcurium Elements,* 31 minutes

Field Trips

A trip to a nuclear reactor would reinforce this unit by allowing the student to see on a first hand basis the practical applications of the material presented in the unit. A trip might be arranged to one of the following Pennsylvania reactor facilities.

1. Shippingport Nuclear Power Plant
   Shippingport, Pa.

2. Peach Bottom Nuclear Power Plant
   York County, Pa.

3. The Pennsylvania State University Breazeale Nuclear Reactor Facility
   University Park, Pa.

4. Three Mile Island Nuclear Power Station
   Middletown, Pa.

5. Berwick Nuclear Power Station
   Berwick, Pa.

UNIT IX

NUCLEAR FUSION

Suggested Time: 2 weeks

OVERVIEW - This unit is designed to acquaint the student with the theory and mechanics of nuclear fusion, and the energy release which accompanies it.

OBJECTIVES

1. The student shall demonstrate theoretically by problem-solving the fusion of light nuclei into heavier nuclei with a resulting mass loss producing energy.

   1.1 The student shall construct nuclear equations to illustrate the mechanics of fusion and calculate from these equations the energy release per fusion event. The student shall also indicate, in the manner requested, the conditions required for the initiation of fusion.

   1.2 The student shall write the carbon cycle equations and the proton-proton equations of stellar fusion processes.

   1.3 The student shall discuss, by means of diagrams and written explanations, current concepts of fusion reactors.

CONTENT

I. Fusion of light nuclei
   A. Carbon cycle
   B. Proton-proton chain

II. The thermonuclear reactions

   A. Deuterium and tritium reactions
   B. Energy release in fusion
   C. Requirements for fusion reactions

III. Attempts to harness fusion

IV. Production of energy in the Cosmos

Films

1. *Research in Controlled Fusion*, 45 minutes
2. *The Magnetic Bottle*, 45 minutes
3. *Operation Crossroads*, 45 minutes
4. *To Imitate the Sun*, 33 minutes
5. *To Battle the Sun*, 5 1/2 minutes

UNIT X

RADIATION HEALTH PHYSICS

Suggested Time: 3 weeks

OVERVIEW - This unit is designed to give the student a basic understanding of the hazards of radiation dangers, the units of radiation dosage, and the decontamination procedures used in case of accidental contamination.

OBJECTIVES

1. The student shall apply data concerning the biological effects of ionizing radiations as presented by the teacher, the text, and resource materials to explain the processes whereby cells are damaged or destroyed by these radiations. The student shall (verbally and by the construction of devices) demonstrate the effects of shielding and radiological decontamination procedures designed to minimize this damage.

    1.1 Given a list of protoplasmic changes in living cells, the student shall identify those effects which are directly attributable to radiation damage.

    1.2 The student shall list in chronological order the general symptoms of persons who have received an acute whole body dosage of radiation.

    1.3 The student shall list on a test the possible results of chronic subacute radiation exposure. In this list, the student shall be required to note the cytological (genetic and somatic) changes which occur.

    1.4 The student shall, when presented with a prepared list of tissues, note whether they are radioresistant, of intermediate radiosensitivity, or radiosensitive.

    1.5 By utilizing the material presented in the class, the student shall illustrate, in the manner required by the teacher, the mechanisms of preferential uptake of radionuclides following ingestion. The student shall list at least three isotopes involved and identify the body organs which tend to accumulate the isotopes listed.

    1.6 Given the physical and biological half-lives of specific radionuclides, the student shall determine mathematically their effective half-lives when utilized as *tracers* in biological systems.

    1.7 In a test situation, the student shall identify the following units of exposure to radiation: Roentgen, RAD, REM, REP, and RBE. (*Identify* means: a denotation of the numerical relation to the basic unit, the roentgen. The roentgen must be identified as ionization in ergs per gram of dry air).

    1.8 The student shall state on a test the maximum permissible dosages to ionizing radiation set by governmental regulatory agencies.

    1.9 The student shall construct diagrams accompanied by a written explanation to show the theories of operation of the devices commonly utilized to record the radiation exposure of individual personnel (specifically, the film badge and the pocket dosimeter).

    1.10 From the materials presented by the teacher, the text, and resource material, the student shall describe the mechanisms of genetic damage due to radiation and the possible effects of this genetic damage.

CONTENT

I. Effects of radiation upon biological organisms

    A. Physical effects
    B. Mutagenic effects
    C. Comparison of acute and chronic exposures

II. Quantitative concepts

   A. Biological half-life
   B. Effective half-life
   C. Quantitative exposure units

      1. Roentgen
      2. RAD (Radiation Absorbed Dose)
      3. REP (Roentgen Equivalent Physical)
      4. REM (Roentgen Equivalent Man)
      5. RBE (Relative Biological Effectiveness)
      6. MPD (Maximum Permissible Dose)
      7. LD 50-30 (Lethal Dose for 50 per cent of the population within 30 days)
      8. MPC (Maximum Permissible Concentration)

SUGGESTED ACTIVITIES

Student Experiments

1. Area monitoring
2. Radiation safety procedures (including decontamination)

Teacher Demonstration

1. Shielding methods
2. Decontamination procedures

Films

1. *Building Blocks of Life*, 29 minutes
2. *Radiation and the Population*, 29 minutes
3. *Radiation Effects in Chemistry*, 13 minutes
4. *Radiation in Biology*, 13 1/2 minutes
5. *Radiological Safety*, 30 minutes
6. *Retirement of the Hallam Nuclear Power Facility*, 35 minutes
7. *Return to Bikini*, 28 1/2 minutes
8. *The Surest Poison*, 29 minutes
9. *Living With a Gloved Box*, 15 minutes

UNIT XI

RADIOISOTOPE APPLICATIONS

Suggested Time: 1 1/2 weeks

OVERVIEW - No course in nuclear science is complete unless the student is made aware of the almost limitless applications of radioisotopes being utilized by industry, medicine, and the other disciplines as a research tool.

OBJECTIVES

1. The student shall use radioactive materials as investigative tools by devising and completing an original laboratory investigation in either the physical or biological sciences, utilizing tracing techniques in the solution of the problem. In conjunction with this investigation, the student shall prepare and submit for grading a formal research report.

1.1 The student shall, on a teacher-prepared test, cite at least two investigations from those presented in class to illustrate the utilization of radionuclides to *normal type tag* molecules in biological and physical investigations.

1.2 The student shall list, on a test, the major sources of available radioisotopes. The lowest acceptable limit of performance shall be three sources.

1.3 Given the physical and biological half-lives of specific radionuclides, the student shall calculate mathematically the effective half-life and the minimum detectable weight of that radionuclide for radiobiological investigations.

1.4 From the materials presented in the class, the student shall list at least three isotopes which are preferentially absorbed and identify the organs which accumulate that isotope.

1.5 Given the pertinent data, the student shall, utilizing the method of dilution analysis, calculate the volume of blood in a hypothetical accident victim and indicate whether or not that patient requires a transfusion.

CONTENT

I. Uses of radioisotopes

II. Stable and radioactive isotopes

III. Isotope production

IV. Labelled compounds

V. Radioautography

VI. Biological applications

VII. Applications in chemistry and physics

SUGGESTED ACTIVITIES

Student Experiments

1. Absorption of P^{32} by plants
2. Absorption of I^{131} by plants
3. Determination of solubility

In conjunction with this unit, each student should be required to undertake an investigation of a laboratory problem involving the use of a radioisotopic *normal type tracer.* This may be an individual project or one involving a group of not more than three students. These are undertaken under the direct supervision of the instructor to insure strict adherence to radiological safety procedures. A formal research report should be submitted in conjunction with this work. A list of possible student investigations is included in the guide sheets.

Films

1. *The Atom and Archaeology*, 25 minutes
2. *The Atom and the Environment*, 22 minutes

3. *The Atom and the Man on the Moon*, 13 minutes
4. *The Atom in Physical Science*, 26 minutes
5. *The Atomic Fingerprint*, 12 1/2 minutes
6. *Atomic Medicine*, 27 minutes
7. *Atomic Revolution in Wood*, 23 minutes
8. *Atomic Search*, 29 minutes
9. *Atoms in Agriculture*, 26 minutes
10. *Brookhaven Spectrum*, 25 minutes
11. *Doorway to Diagnosis*, 24 1/2 minutes
12. *Down on the Farm*, 29 minutes
13. *Extracorporeal Irradiation of Blood and Lymph*, 7 1/2 minutes
14. *Fabrication of SNAP-7D Fuel Sources*, 12 minutes
15. *Controlled Photosynthesis*, 24 minutes
16. *Farm Fresh to You*, 13 1/2 minutes
17. *First Chemical Separation of Lawrencium*, 17 minutes
18. *Desalting the Seas*, 17 minutes
19. *The Bitter and the Sweet*, 29 1/2 minutes
20. *Project Gasbuggy: The Resourceful Atom*, 14 1/4 minutes
21. *Radioisotope Scanning in Medicine*, 16 minutes
22. *Radioisotopes in Biology and Agriculture*, 26 minutes
23. *Roundup*, 18 1/4 minutes
24. *Sandra Spinoff*. 15 minutes
25. *Short Lived Radioisotopes in Nuclear Medicine*, 27 minutes
26. *Space and the Atom*, 27 1/2 minutes
27. *Testing for Tomorrow*, 29 minutes
28. *Tracing Living Cells*, 29 minutes
29. *The Weather Eye*, 13 minutes
30. *The Fresher the Better*, 13 1/2 minutes
31. *Harnessing the Rainbow*, 27 minutes
32. *Harvest of an Atomic Age*, 20 minutes
33. *Heavy Particle Beams in Medicine*, 11 minutes
34. *The Immune Response*, 27 minutes
35. *Isotopes in Environmental Control*, 14 minutes
36. *The Living Solid*, 27 minutes
37. *Neutron Activation Analysis*, 40 minutes
38. *Nuclear Fingerprinting of Ancient Pottery*, 20 minutes
39. *Nuclear Innovations in Process Control*, 17 minutes
40. *Nuclear Power for Space - SNAP-9A*, 12 minutes
41. *Nuclear Reactor Space Power Systems*, 8 minutes
42. *The Nuclear Witness: Activation Analysis in Crime Investigation*, 28 minutes
43. *Opportunity Unlimited: Friendly Atoms in Industry*, 28 minutes
44. *Pax Atomics: SNAP-7 Terrestrial Isotopic Power Systems*
45. *Persimmon: A Nuclear Physics Experiment*, 16 minutes
46. *The Radioisotope Powered Cardiac Pacemaker*, 21 1/2 minutes

General Films:

1. *Atoms in the Marketplace*, 28 minutes
2. *Challenge of the Future*, 29 minutes
3. *Energy - The American Experience*, 28 1/2 minutes
4. *Preparing for Tomorrows World*, 26 minutes
5. *Go Fission*, 14 minutes
6. *The Heart of the Matter*, 6 minutes

7. *Horizons Unlimited*, 37 minutes
8. *Underground Nuclear Weapons Testing*, 28 1/2 minutes
9. *When the Circuit Breaks*, 27 1/2 minutes
10. *The Wooden Overcoat*, 14 minutes
11. *Your Place in the Nuclear Age*, 26 minutes
12. *The Many Faces of Argonne*, 60 minutes
13. *The Mighty Atom*, 27 minutes
14. *Nature's Forge*, 29 minutes
15. *Nuclear Spectrum*, 28 minutes
16. *On the Move*, 28 minutes
17. *People and Particles*, 27 minutes

VII GUIDE SHEETS TO ACCOMPANY SYLLABUS FOR NUCLEAR SCIENCE

The following guide sheets should be used at the discretion of the teacher. However, we recommend that the problem sets be emphasized.

Unit 1

The Atomic Theory

1. Trace historically the broad concept of the atomic structure of matter.
2. Which men revived this concept during the Renaissance?
3. Who is given credit for the modern atomic theory?
4. How did he change this concept into a concrete theory?
5. How correct were Dalton's atomic weights?
6. What was the four-element theory of matter?
7. Describe Aristotle's concept of matter.
8. How did the work of Priestly and Lavoisier cause the four-element theory to be abandoned?
9. State Lavoisier's concept of an element.
10. How many elements did Lavoisier list? How correct was he?
11. How many elements are known today?
12. What is a compound?
13. Define the term transmutation.
14. Discuss the present concept of an element.
15. Discuss in detail the modern concept of an atom.
16. Describe and illustrate several of Dalton's symbols for the elements.
17. How did Berzelius improve the symbols for elements?
18. How is the formula of a compound written?
19. Who is given credit for formulating the periodic law?
20. Wherein did the periodic chart have its most striking successes?
21. What elements were discovered to fill in gaps in the periodic chart which exactly followed Mendeleev's predictions?
22. Describe what we mean by periods and groups in the periodic table.
23. Why do we have group 0 in the chart?
24. Why are the Lanthanides (rare earths) grouped together in Group III A, Period 6?
25. Name the members of the Lanthanide Series.
26. Discuss the Actinide Series and name its members.
27. What is the size of a molecule (Kelvin's measurement)?
28. What is Avogadro's Law?
29. What is a mole (gram molecular weight)?
30. What is STP (Standard Temperature and Pressure)?
31. What is a Molar Volume (The volume of one mole of an inclosed gas at STP)?
32. What weight of H_2 would make a molar volume? Cl_2? Kr?
33. What is the Avogadro number?
34. How, by using the Avogadro number, would you find the weight of a single molecule in grams?
35. Describe Brownian Movement and its cause.
36. Compare the number of atoms per volume in liquids, solids, and gases.
37. What is the weight in grams of a single H atom? Would this be the approximate weight of a proton?
38. What is the weight in grams of a single uranium atom?
39. What is the approximate diameter of an atom?
40. What is an Angstrom Unit?

Unit 1

Problem Set

A. Show the electron configurations of the following elements:

1. Cr
2. Cl
3. Au
4. He
5. Sr
6. S
7. Rh
8. P
9. K
10. Zr

B. Describe the Bohr Theory

C. Discuss the Pauli Exclusion Principle

D. Why are C and Si chemically similar?

E. Compare Electrovalence and Covalence

F. Exponents: Solve the following problems

1. $(1\text{X}10^{-24})$ $(6\text{X}10^{10})^2$. $(1.5\text{X}10^{50})$
2. $\frac{(0.000069)^2(16928)^4}{0.0000000001}$
3. $(3)(0.0000009)$
4. $4\sqrt{\text{X}10^{16}}$
5. $10^{2/10}$

Unit 2

Atomic Particles and Electromagnetic Radiations

A. The Nature of Electricity

1. Describe the electric charges produced by rubbing glass with silk and hard rubber with fur. Why do these charges seem to be different?
2. Discuss what we mean by positive and negative charges.
3. What is static electricity?
4. What is dynamic electricity?
5. What is a volt?
6. What is an ampere?
7. What is an ohm?
8. Describe the direction of flow of electric current.
9. Differentiate between alternating and direct current.
10. What is a cathode? An anode?
11. How are cathode rays produced?
12. What is the effect of a magnetic field on cathode rays?
13. What are cathode rays?

B. Fundamental Particles

1. Where in the atom is the electron located?
2. Describe the magnitude of the negative electric charge (the electron).
3. What is the mass in grams of the electron?
4. Compare the mass of the electron as compared to the mass of hydrogen.
5. Upon what does the mass of the electron depend?
6. What do we mean by the term rest mass?
7. What is the radius of an electron?
8. What is a positron?
9. What is the mass of a positron?
10. What is the average life of a positron?
11. What happens when a positron and electron unite?
12. What is annihilation radiation?
13. What is the general rule for *normal type antiparticles*?
14. What is an antiproton?
15. Describe Roentgen's discovery of the X-ray.
16. Describe the properties of Roentgen's X-ray.
17. What is an anticathode?
18. What are characteristic X-rays?
19. What is the general wavelength of X-rays?
20. Discuss why crystals are used as diffraction gratings.
21. Who discovered radioactivity? How was it discovered?
22. Who first called it *radioactivity?*
23. What are alpha particles?
24. What are beta particles?
25. Compare the penetrating power of alpha and beta particles.
26. What are gamma rays?
27. Who discovered the neutron?
28. Why does a neutron not produce a track in a cloud chamber?
29. Account for the high penetrating power of the neutron.
30. Compare the neutron and antineutron.
31. Discuss Pi, Mu and K mesons. Include their mass and charge.
32. What is a neutrino?
33. What are cosmic rays?
34. In what form do cosmic rays reach the earth?

Unit 3

The Dualistic Nature of Radiant Energy

1. Essentially, what is energy?
2. How can energy be converted from one form to another?
3. What is the result of a very large amount of energy being produced in a very short time?
4. Define radiant energy.
5. How did Newton try to explain light?
6. Discuss the wave theory of light.
7. Why was Newton opposed to the wave theory?
8. How does optical diffraction suggest that the wave theory may be correct?
9. Discuss optical interference and its relation to the wave theory.
10. What do we mean by wavelength? What is the wavelength of red light?
11. How does wavelength control color?
12. What radiations would be invisible to the eye?

13. Discuss the range of electromagnetic waves.
14. How are all these radiations fundamentally the same?
15. What are Hertzian waves? How are they produced?
16. Which color is the most efficient radiation absorber?
17. Discuss the theory of the ideal *black body*. Does this exist?
18. Discuss Planck's theory concerning how a body absorbs or emits energy.
19. What is a quantum of energy?
20. Give Planck's formula for determining the quantum of energy for a given frequency.
21. What is Planck's constant?
22. State the formula for the exact relationship between the energy quantum and the wavelength.
23. What is an electron volt?
24. Give the relationship between the electron volt and the erg.
25. What is a kilovolt (keV)? A Megavolt (MeV)?
26. Explain what Einstein meant by the term photon.
27. What is the Compton effect?
28. What happens to X-rays when they interact with electrons?
29. What is meant by wave-particle duality?
30. State deBroglie's equation showing that a particle m, moving with a velocity v, is associated with waves of length.
31. What must the size of particles be in order that they exhibit the property of waves?
32. Explain why crystals can be used as diffraction gratings.
33. How did Thompson prove that electrons show wave properties?
34. Give one use of the wave properties of electrons.
35. In respect to wave or particulate properties, how do we refer to electrons? Neutrons? Atoms? Molecules? Light?
36. State and explain Heisenberg's uncertainty principle.
37. What was the theory of ether?
38. What is the velocity of light in miles per sec?
39. What is the velocity of light in cm/sec?
40. Is this velocity a constant?
41. Note carefully the Lorentz equation for the variation of mass with velocity.
42. Why is the above equation taken to be the correct representation of the effect of motion on the mass of an electron?
43. State and discuss the Einstein mass energy equation.
44. Discuss the implications of this equation.
45. Discuss how this equation changed our original concept of the relationship of mass and energy.
46. Why had changes in mass never been detected in chemical reactions?
47. What is an atomic mass unit?
48. How do we calculate the mass of any atom in grams?
49. One atomic mass unit is equal to what amount of energy in electron volts?
50. Using the above information, how can you quickly calculate the energy equivalent of any given mass?
51. Correlate the above information using the Einstein mass-energy equation.
52. What is annihilation radiation?
53. When an electron-positron pair annihilate each other, what is formed?
54. How does electron-positron annihilation substantiate the Einstein mass-energy relationship?

Unit 3

Problem Set 1

1. Determine the wavelength of a photon with a frequency of 3 X 10^5 vps.

2. What is the wavelength of a photon with an energy of 1.5 MeV?

3. Visible red light? = 7.6 X 10^{-5} cm.

   a. Determine frequency
   b. Determine its energy

4. What is the energy in MeV of a β^- particle traveling at 2.86 X 10^9 cm sec $^{-1}$?

5. Calculate the frequency of a photon which has an energy of 1.99 X 10^{-8} ergs.

6. What is the wavelength of a 454-gram baseball traveling at a speed of 200 meters/sec.?

7. Calculate the energy of a proton accelerated to 2.5 X 10^{10} cm/sec.

8. Using the deBroglie formula, prove that the rest of the mass of an electron is equal to zero.

9. Why must we assume that radiation has a dualistic nature?

10. Calculate the annihilation radiation produced by a proton-antiproton impact.

Problem Set 2

Quantum Mechanics: Relativity

1. If a 5 g ball bearing is accelerated to a velocity of 2.8 X 10^8 cm/sec. what will its mass be at that velocity?

2. If the legendary Hiawatha shoots a 30 cm arrow with his magic bow at a velocity of 0.8C, what length will the arrow be at this velocity?

   a. The rest mass of this hypothetical arrow is 50 g. What is its mass at 0.8C?

3. What is the wavelength of a 1 mg mass moving at 2 X 10^7 cm/sec.?

4. What is the frequency of a 10^{-8} cm gamma ray?

5. What is the energy of a photon with a wavelength of 10^{-7} cm? 10^{-3} cm?

6. How can two photons have different energies, even if their speed is the same, provided they have different wavelengths?

7. What is the wavelength of a photon with a frequency of 10^{-2} vps?

8. Describe the Compton Effect.

9. Using the Einstein equation, explain how we have altered our concept of the relationship of mass and energy.

Unit 4

The Structure of the Atom

1. How did most of the nineteenth century scientists regard the atom?
2. Describe why J. J. Thomson's concept was important, even if it is no longer accepted.
3. Describe the results of Rutherford's experiment in passing Alpha particles through metal foil.
4. How did Rutherford describe this phenomenon?
5. As a result of this experiment, how did Rutherford describe the atom?
6. How can we account for this scattering of alpha particles?
7. Why were such a small number of alphas repulsed?
8. In describing the atom, what is the Z number?
9. Describe the number of positive and negative charges on an atom.
10. About what part of the total atomic weight of an atom is composed of positive charges?
11. How did the above information tell us approximately the number of naturally occurring elements? Is this calculation true?
12. Where is the mass of an atom concentrated?
13. What is the radius of the atomic nucleus?
14. What is the radius of an electron?
15. What actually accounts for the nuclear mass?
16. Of what does an atom mostly consist?
17. Describe the relationship between the number of positive charges on an atom and the atomic number.
18. What is the relationship between the number of electrons and the atomic number?
19. What is an orbital electron?
20. Actually, what is a proton?
21. To which nucleus is the Alpha particle identical?
22. What is an ion?
23. How is an ion formed?
24. What is an ion pair?
25. What is a neutron? Describe its properties.
26. Now describe the three fundamental particles which make up an atom.
27. What do we mean by the word nucleon?
28. What is the A number of an atom?
29. What is the Z number of an atom?
30. How can you calculate the number of neutrons in a nucleus, using the A and Z numbers?
31. What is an isotope?
32. How can we change one atom into an atom of another element?
33. What do we mean by binding energy?
34. Discuss the binding energy of an alpha particle.
35. What does a high binding energy indicate? A low binding energy?
36. Discuss the concept of electron energy levels.
37. How can we cause electrons to change their energy levels?
38. What must an electron lose to drop from a higher to a lower energy level?
39. What is the ground state of an electron?
40. What is the excited state of an electron?
41. What is a characteristic X-ray?
42. How may characteristic X-rays be used to identify unknown atoms?
43. What is bremsstrahlung?
44. Explain the concept of nuclear energy levels.
45. What type of radiation is given off by changes in nuclear energy levels?
46. What is nuclear *spin*?

Unit 4

Problem Set

1. Determine the nuclear radius of C^{14} (A = 14.007682) and Ra^{222}(A = 222.0845).

2. Determine the volume of the following nuclides:

   a. $^{1}_{1}H$

   b. $^{2}_{1}H$

   c. $^{235}_{92}U$

   d. $^{186}_{74}W$

   e. $^{168}_{68}Er$

3. What is the nuclear radius of a proton?

4. What is the radius of the nucleus of an atom (A=26) when it is accelerated to 2.8×10^{10} cm sec^{-1}?

Unit 5

Radioactive Elements

1. Who first discovered radioactivity? When?
2. What methods of detection were used by these early workers?
3. Describe the piezoelectric device used by Dr. Curie to undertake quantitative measurements of radioactivity.
4. Compare the activity of Polonium with Uranium.
5. Why was Radium similar in its chemical properties to Barium?
6. How much Radium was secured by the Curies from the ton of pitchblende ore they were given?
7. Discuss the number of radioelements now known.
8. What is Uranium X?
9. Draw and discuss the decay - recovery curves of Thorium and ThoriumX.
10. Discuss in detail Rutherford and Soddy's Theory of Radioactive Disintegration.
11. How does this explain Radium X and Thorium X?
12. What was the cause of the *"Radium induced emanations"* first described by the Curies?
13. How do physical conditions affect the rate of radioactive disintegration?
14. How did Lord Rutherford interpret the results of the above question?
15. Does the fact of radioactive decay disestablish our interpretation of an element? Explain.
16. How may radioactive decay products be separated?
17. What is a *carrier?*
18. What is used as a carrier for Polonium, Barium, Radium? Why?
19. What are parent and daughter nuclides?
20. Describe the recoil method of nuclide separation.
21. This method may be used with which type of radioactive decay?
22. What do we mean by the statement that radioactivity diminishes in an exponential (logarithmic) manner?
23. State and explain the formula concerning radioactive decay.
24. Why do we use the negative sign in the above equation?
25. What is the radioactive decay constant?

26. Give the equivalent exponential form of the above equation (decay equation).
27. Discuss the factor used to convert natural to conventional logarithms, and give the converted decay equation.
28. What is the minimum change of activity which will work in the above equation? Is this satisfactory?
29. How may the mean or average life of an atom be calculated from the half-life?
30. Can you tell exactly which atoms will disintegrate within any given time?
31. Give and discuss the equation for radioactive equilibrium.
32. Explain the equation for radioactive equilibrium of any decay chain nuclide.
33. What does this show concerning the ratio of the amounts of any two members of a disintegration series?
34. Discuss the concept of half-life?
35. How may half-life be calculated from the decay constant?
36. Name and describe the three natural radioactive series.
37. For what types of radioelements are decay rates difficult to calculate? Why?

Problem Set 1 - Half-Life

DATE	TIME	COUNT RATE OF SAMPLE
27 June	1:35 PM	8754 c/m
27 June	4:50 PM	7553 c/m
28 June	8:05 PM	3808 c/m
28 June	3:20 PM	2750 c/m
29 June	9:50 AM	1195 c/m
30 June	8:20 AM	437 c/m
30 June	4:35 PM	300 c/m
1 July	9:50 AM	138 c/m
1 July	3:35 PM	105 c/m

CALCULATE THE STANDARD DEVIATION, AND THEN GRAPH THIS INFORMATION ON NORMAL AND SEMI LOG PAPER. FROM THE SECOND GRAPH, CALCULATE THE DECAY CONSTANT AND THE HALF-LIFE.

Problem Set 2

Experimental Data

Half-Life Determination

DATE	I^{131}	P^{32}
1/11	3562	10480
1/14	2760	8673
1/15	2612	8503
1/16	2383	8042
1/17	2287	7850
1/18	2088	7342
1/21	1542	6401
1/23	1322	5794
1/24	1226	5503
1/25	1166	5199
1/29	819	4540
1/30	737	4166
1/31	684	3942
2/1	600	3832
2/5	512	3185
2/6	403	3052
2/7	385	2769
2/8	343	2797
2/11	255	2397
2/12	263	2274

Determine the half-lives both graphically and arithmetically. Determine the Lambda values.

What is the mean life of the atoms of each isotope?

Define the following: Biological half-life, effective half-life.

Problem Set 3

Experimental Half-Life

DATA

Date	Sample 1	Sample 2
2/6	3356	3742
2/7	2542	2905
2/10	2590	2827
2/11	2260	2587
2/13	1983	2069
2/14	1857	1990
2/17	1300	1473
2/18	1269	1326
2/20	1034	1187
2/21	996	1053
2/25	606	750
2/26	621	669
2/27	600	611

FIND: Half-Life =

λ =

Unit 6

The Measurement of Nuclear Radiations

1. Upon which discovery of Becquerel are some of the most useful procedures for the detection of radiation based?
2. Why are nuclear radiations also called ionizing radiations?
3. How do radiations cause ionization?
4. What is an ion-pair?
5. What is specific ionization?
6. How can we increase ionization for particles of the same mass?
7. For particles of the same energy, how does specific ionization change with speed?
8. Compare the specific ionization of an alpha with a beta of the same energy.
9. State the reason for the above answer.
10. What is total ionization?
11. Upon what is total ionization dependent?
12. How do gamma rays and other electromagnetic radiations produce ionization?
13. Would the specific ionization of a gamma ray be high or low? Explain why.
14. Do the same for the total ionization caused by a gamma ray.
15. Upon which principle do most electronic detectors of radiations operate?
16. In the above detectors, upon what does the size of the current pulse depend?

A. The Ionization Chamber

1. Explain how the speed of the ions toward the electrodes varies with the applied potential (voltage).
2. For what particles can the ionization chamber be used?
3. Sketch and discuss the construction of an ionization chamber.
4. What is an integrating ionization chamber?
5. What is a non-integrating ionization chamber?
6. Why is the ionization chamber an excellent instrument for counting alphas, protons, and neutrons?
7. What is a scaler? What is its purpose?
8. How does the quartz-fiber electroscope operate?

B. The Proportional Counter

1. What is the Townsend Avalanche?
2. What is the gas-amplification factor?
3. What gases are used to fill proportional tubes?

C. Geiger-Muller Counters

1. Diagram the construction of a G-M tube.
2. Why is a high potential maintained in the tube?
3. Describe the difference in the avalanche in the proportional and G-M counters.
4. What is the G-M operating voltage range?
5. Explain the problem of resolving consecutive impulses in this type of tube.
6. What do we mean by quenching?
7. What may be used to quench the tube?
8. What limits the life of self-quenching tubes?
9. Why are chlorine-quenched tubes superior to organically-quenched tubes?
10. What is resolving time?
11. What is a scaler-ratemeter?

12. For what particles are G-M tubes usually used?
13. What is meant by the geometry of a sample?
14. Upon what general principle do scintillation counters operate?

D. The Wilson Cloud Chamber

1. How do ionizing radiations affect the condensation of supersaturated vapor?
2. What happens when an ionizing particle enters the saturated vapor?
3. What are condensation nuclei?
4. What is a cloud track?
5. Describe the tracks of alpha particles.
6. What liquid is presently used to form a saturated vapor in cloud chambers?
7. Describe the track of an electron (beta particle).
8. Describe the diffusion cloud chamber.
9. Describe how particle tracks affect a photographic film.
10. Compare the track lengths of film plates to those of cloud chambers.

Unit 7

Particle Accelerators

1. Define the term *transmutation.*
2. How did the development of modern ideas about the atom change our thinking about the possibility of achieving transmutations?
3. Who achieved the first deliberate artificial transmutation?
4. Exactly what were Rutherford's results?
5. What elements emit protons when bombarded with alpha particles?
6. As a general rule, what do nuclear reactions involve?
7. Why was the Cockroft-Walton machine historically important?
8. Diagram and label the Van de Graaff electrostatic generator.
9. Describe how this machine works.
10. What voltages have been reached with this apparatus?
11. Name one important advantage of this machine.
12. Describe the construction of the drift-tube type of linear accelerator.
13. Describe the construction of the cyclotron.
14. What forces the particles to move in a cyclotron?
15. How do these particles move? (Describe their path).
16. How are the radius of the path and the particle's velocity related?
17. What is the function of the oscillator?
18. Which accelerator is used for electron acceleration?

To the Teacher:

Due to the complexities of the other types of accelerators, guide questions would be needlessly complex. It is suggested that you prepare simple lectures covering the betatron, electron synchrotron, proton synchrotron and others. The texts listed in the bibliography will give you the desired information.

Unit 8

Nuclear Fission

1. What property of nuclear fission enables it to be self-sustaining?
2. What do we mean by a fissile isotope? Name a few.
3. In fission, what happens to the fissile isotope?
4. In Uranium fission, what amount of energy is liberated?
5. What produces this energy?
6. What weight in A.M.U. is destroyed here?
7. Calculate the amount of energy created here, using the formula EmeV=M x 931.
8. Now calculate this using the Einstein equation.
9. What is binding energy?
10. Give the total energy released by the fission products of one Uranium atom.
11. Discuss the approximate distribution of the fission fragments discussed above.
12. Draw and describe the curve for the isotopes produced by U^{235} fission.
13. In the curve you have just drawn, why did you plot mass numbers instead of atomic numbers?
14. In how many different ways may the uranium nucleus split?
15. From where do the neutrons thrown off in fission come?
16. What are prompt neutrons?
17. What are delayed neutrons?
18. How may the nuclear mass produce instability?
19. The theory of the liquid drop nucleus will be discussed in class.
20. Discuss the concept of fission due to nuclear energy levels.
21. Define the critical energy for fission.
22. In Uranium fission, what happens to the electrons? What effect does this have on the fragments?
23. What type of activity do the fission fragments show? Why?
24. What is a fission decay chain?
25. How many possible fission fragments are there?
26. How many radionuclides (radioisotopes) may be produced by the decay of these fragments?
27. How much time is required for the actual fission process?
28. Why is Uranium-238 not used to make the atomic bomb?
29. Why was Uranium-235 selected?
30. How much energy is liberated by the fission of 1 kilogram (2.2 lbs.) of U-235?
31. What other element was considered to be an alternate to Uranium for the bomb?
32. What is a moderator?
33. What substances are suitable for moderators?
34. What is the reproduction factor of a fission system?
35. What do we mean by the critical size of a system?
36. What is a subcritical size? Supercritical size?
37. What is a neutron reflector?
38. How probable is it that a nuclear reactor will explode?
39. What is a control rod? Of what material are control rods composed?
40. How is the power of a reactor increased?
41. How is a reactor shut down?
42. How is a reactor started up?
43. How is Plutonium-239 produced in a reactor?
44. How would the Uranium-239 and Plutonium-239 be separated?
45. Compare the nuclear pile and the nuclear bomb.
46. What is the result of a large amount of energy released in a short time within an enclosed space?
47. What are the two main requirements for a fission bomb?

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48. Why is the process of slow neutron fission undesirable for a bomb?
49. Why is it impossible to prevent a chain reaction in a supercritical mass?
50. How is this criticality problem solved?
51. Describe the gun barrel bomb.
52. Describe the implosion or critical density bomb.
53. How does the reflector in a bomb decrease the critical mass?
54. What was the explosive power of the first A-bomb?
55. What temperature accompanies an atomic explosion?
56. Describe the reasons for the effects of the A-bomb.
57. To what is the liberation of energy in the fission bomb due?
58. How does this relate to the fusion of light nuclei?
59. What is a thermonuclear reaction?
60. How can two nuclei overcome the electrostatic repulsion between their two positive charges?
61. How much energy is required to make the nuclear reaction occur?
62. What temperature must be reached to be equivalent to this energy?
63. What is plasma?
64. Describe the Carbon-cycle fusion reaction.
65. Discuss in detail the proton-proton fusion reaction.
66. What nuclei are suitable for fusion reactions on earth?
67. What weight of deuterium is available on earth?
68. How are the temperatures necessary for fusion attained?
69. Discuss the construction of the H-bomb.
70. In outline, of what does a nuclear reactor consist?
71. What are the components of the reactor core?
72. Describe the two methods of reactor control.
73. What must be taken into consideration in designing a reactor?
74. Define the term thermal reactor.
75. How are neutrons in such a reactor slowed down?
76. What is the main advantage of the thermal reactor?
77. Discuss the major drawback of a thermal reactor.
78. What is a fast reactor?
79. What are the disadvantages of a fast reactor?
80. What is a *breeder reactor*?
81. What is an intermediate reactor?
82. Of what elements may the nuclear fuel be composed?
83. What per cent of Uranium is U-235?
84. Discuss which isotopes may undergo fission.
85. For what is Th-232 used?
86. Discuss solid reactor fuel elements.
87. Discuss radiation damage to reactor fuel elements.
88. What is a reactor poison?
89. What are the basic requirements for a moderator?
90. What materials are suitable for moderators?
91. Discuss why water is commonly used as a moderator.
92. What is one drawback of water as a coolant?
93. What is the best material available as a neutron moderator?
94. Why is beryllium used as a moderator in special cases only?
95. What form of carbon is used as a moderator?
96. What materials may be used as reactor coolants?
97. What is a heat exchanger?
98. What is a regenerative reactor?
99. Discuss the production of Uranium-239 in a regenerative reactor.
100. What is a breeder reactor?
101. How is it possible to increase our stockpile of Plutonium-239 in a breeder reactor?

102. How may the fertile material be placed in a reactor to produce Plutonium-239?
103. Name the three types of reactors.
104. What is a research reactor?
105. Discuss and describe a thermal column.
106. What is a spent fuel element?
107. Of what use are spent fuel elements?
108. How may we dispose of the fission waste products?

Problem Set

Calculate the energy release per fission event for the following reactions:

a. $^{235}_{92}U + ^{1}_{o}n \rightarrow ^{95}_{42}Mo + ^{189}_{57}La + 2\,^{1}_{o}n + 7\,^{o}_{-1}e$

b. $^{235}_{92}U + ^{1}_{o}n \rightarrow ^{140}_{56}Ba + ^{89}_{36}Kr + 5\,^{1}_{o}n$

c. $^{235}_{92}U + ^{1}_{o}n \rightarrow ^{150}_{60}Nd + ^{77}_{32}Ge + 9\,^{1}_{o}n$

Nuclear Masses:

$^{235}U = 235.049$

$^{95}Mo = 94.9058$

$^{139}La = 138.9061$

$^{1}_{o}n = 1.0087$

$^{o}_{-1}e = 0.00055$

$^{140}Ba = 139.9544$

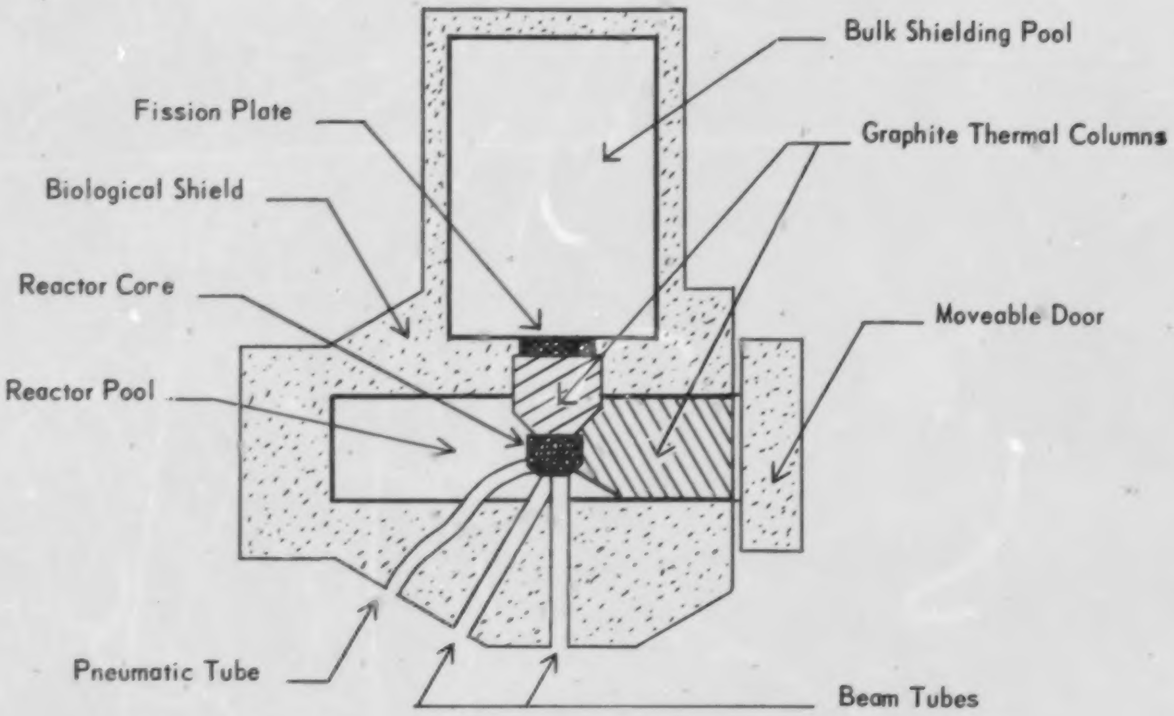
$^{89}Kr = 88.9448$

$^{150}Nd = 149.9679$

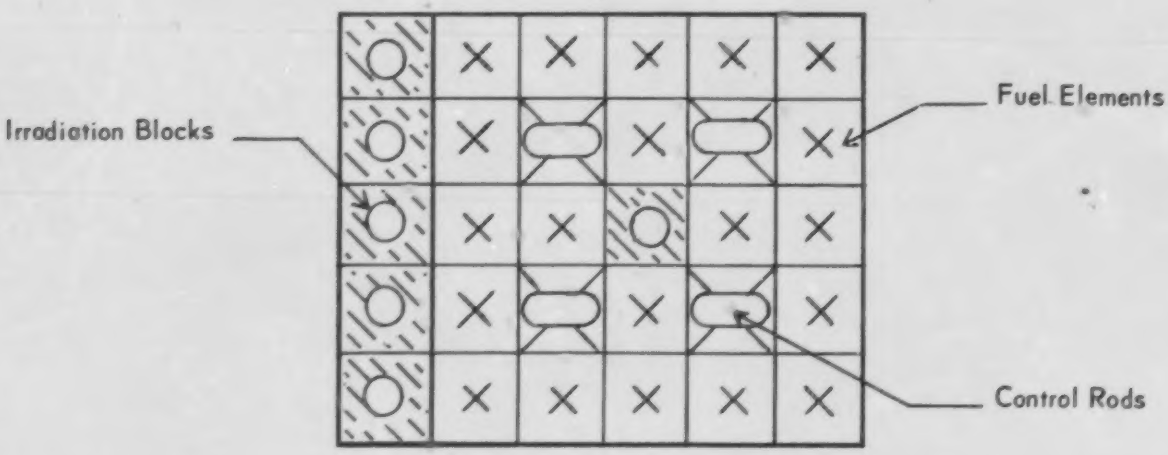
$^{79}Ge = 76.9484$

A TYPICAL NUCLEAR RESEARCH REACTOR

TOP VIEW



THE REACTOR CORE



Unit 9

Fusion

1. Prior to 1939 which method of releasing nuclear energy was considered the most promising?
2. Why does the fusion of light nuclei result in a liberation of energy?
3. How can nuclei of low mass number be brought together in order to have them undergo fusion?
4. To be of practical value, what properties must fusion reactions possess?
5. Discuss the Hemholtz theory concerning solar energy production. Why is it now rejected?
6. Discuss Eddington's two alternate theories of solar energy production.
7. What are thermonculear reactions?
8. What property must particles possess in order to overcome the electrostatic repulsion barrier in order to undergo fusion?
9. What energy is required to make nuclear reactions of hydrogen isotopes occur?
10. What temperature would be required to achieve this energy?
11. What is plasma?
12. What is the Maxwellian distribution of energies among the molecules of a gas?
13. How would this Maxwellian distribution affect a plasma?
14. Give the nuclear equations for and discuss the carbon cycle.
15. Give the nuclear equations for and discuss the proton-proton chain.
16. What factor determines which of the above two reactions occurs?
17. Which of these two reactions predominate in the sun?
18. What weight of the sun's hydrogen is converted into helium annually?
19. What will happen to the sun after five per cent of its hydrogen has been consumed? How far in the future will this be?
20. Why would the carbon cycle and proton chain be only of limited value for a bomb?
21. Which isotopes were chosen as showing the most promise to be fusile?
22. What is the ratio of deuterium to hydrogen in all natural waters?
23. What was the 1976 price of heavy water (deuterium oxide)?
24. Why are accelerators not used as a means of producing fusion?
25. Discuss differences in control of the fusion reaction in the bomb and the fusion reactor.
26. What conditions are necessary for a self-containing nuclear system?
27. What are the problems of plasma confinement?
28. What is a *magnetic bottle?*
29. Describe the pinch effect.
30. Discuss the stellerator.

Unit 10

Radiation Health Physics

1. Describe the results of Pierre Curie's voluntary exposure to Radium emanations.
2. When did workers begin to pay attention to radiation hazards?
3. Which agency is now responsible for establishing radiation exposure limits in the U.S.?
4. What is the function of Health Physics?
5. What are the responsibilities of the health physicist?
6. How do neutrons cause biological damage?
7. How do radiations affect body cells?
8. How do damaged body cells affect the circulatory system?
9. Describe the effects of radiations on the process of mitosis.
10. What is the relationship between radiation exposure and the growth of cancers?

11. Why may individuals become unconsciously exposed to excessive radiation?
12. What is the effect of very large doses of radiation upon the human system?
13. Describe in detail the effects of prolonged (chronic) exposure to radiation.
14. Describe in detail the results of acute overexposure to radiation.
15. What radiation effects may not become apparent for years following acute doses?
16. Why is susceptibility to infection a symptom of radiation sickness?
17. To what are the effects of radiation upon the blood due?
18. What organs are considered to be radiosensitive? Radioresistant? Intermediate?
19. Which elements are bone seekers?
20. Why are these bone-seeking elements harmful?
21. What is the main consideration in determining the biological hazard of a given element?
22. Explain the meaning of biological half-life.
23. Describe the meaning of effective half-life.
24. What type of elements present the greatest potential internal hazard?
25. Give the example of the above question given by Glasstone, using I-131 as the example.
26. Define the Roentgen.
27. Define the Rad.
28. Define the Rep.
29. Define the Rem.
30. Discuss the RBE.
31. Explain the factors determining the RBE for a given radiation.
32. Define the type of dose intimated by the Rem, Rad, and Roentgen.
33. What is the reason for the recovery by the body from small doses of radiation?
34. List the sources of background radiation.
35. In the U.S., what is the dosage from natural background?
36. What is the mpd (maximum permissible dose)?
37. What is a normally lethal dose of radiation?
38. Discuss the difficulty of assessing total body dosage?
39. Define the mpd in Rems.
40. What is mpc (maximum permissible concentration)?
41. List the mpc for: Plutonium-239; Strontium-90.
42. Describe the construction of the film badge.
43. How are neutrons detected by a film badge?
44. Describe the pocket of air dosimeter.
45. How are neutrons detected by the air dosimeters?
46. Describe the pocket gamma dosimeter.
47. Why do we take urine samples from radiation workers?
48. Discuss the blood tests used to diagnose overexposure.
49. Why is lead a poor absorber for high energy betas?
50. Discuss the method used for gamma absorption.
51. What type of concrete is used for reactor shielding?
52. What is a gene?
53. How do the genes influence hereditary characteristics?
54. What is a mutation?
55. Discuss the three possible ways in which radiations may cause mutations.
56. Discuss the relationship between the frequency of gene mutations and the gonadal dose.
57. Discuss the types of deleterious mutations.
58. What is the dosage which should double the rate of spontaneous mutations?
59. Differentiate between somatic and genetic mutations.
60. How are gamma rays being used to attempt to produce improved plant species?

Unit 11

Radioisotope Applications

1. Why have radioisotopes only recently come into use as a research tool?
2. Compare the chemical properties of all the isotopes of a given element.
3. How does a trace of a radioisotope label a compound?
4. How was Carbon-14 used to trace plant respiration?
5. How were isotopes used to explain fertilizer uptake?
6. How were they used to explain the mechanics of blood mixing after transfusions?
7. How was Oxygen-18 used to explain photosynthesis?
8. Describe the first application of a radioisotope to biological research.
9. What is a stable isotope?
10. Why, until recently, was the use of isotopes restricted?
11. How many stable isotopes are now available?
12. How are these stable isotopes obtained?
13. What is the usual source of radioactive isotopes?
14. How do we obtain radionuclides which cannot be conveniently derived by placing stable isotopes in a neutron flux?
15. Why are radioisotopes rather than stable isotopes often selected to apply in a research problem?
16. Why are alpha emitters unsatisfactory for use as biological tracers?
17. How does half-life determine the usefulness of an isotope?
18. What is the relationship between the life of a radioisotope and the energy of the emitted particle?
19. What is the greatest advantage of a stable isotope?
20. How are stable isotopes detected?
21. Why is it difficult to work with the radioactive isotopes of nitrogen and oxygen?
22. Why is tritium difficult to work with in living organisms?
23. Describe the production of Carbon-14 and Carbon-11.
24. Describe the nuclides available for biological research.
25. Discuss the rate of disintegration of a radioelement.
26. What is the smallest amount of activity which can satisfactorily be counted?
27. Give and explain the formula for determining the minimum number of radioactive atoms which can be conveniently detected.
28. How can the above number be converted into grams of an isotope?
29. How is this weight of an isotope related to mass number and half-life?
30. Define specific activity. How is it expressed?
31. What is a labeled compound?
32. What is biosynthesis?
33. What types of compounds are labeled by biosynthesis?
34. How are labeled acids produced?
35. Describe the density methods of determining the presence of deuterium.
36. What is autoradiography? Radioautography?
37. What are the main uses of isotopic tracers in biology and chemistry?
38. Which radioisotopes have been used to perform research on the blood?
39. Describe the use of radioisotopes to show restricted circulation.
40. How has this isotope been used to show heart action?
41. What is preferential absorption? How is this important?
42. How is Iodine-131 used to diagnose hyperthyroidism?
43. How may this isotope be used to treat cancer of the thyroid?
44. How may isotopes be used for tumor location?
45. Describe the use of Phosphorus-32 for the treatment of polycythemia and leukemia. Is this method an actual cure?

46. Why is Cobalt-60 replacing both Radium and X-rays for cancer treatment?
47. Discuss several industrial applications of isotopes.
48. Describe isotopic dilution analysis.
49. Describe activation analysis.
50. Describe tracer analysis.
51. Describe the use of an isotope to show the new standard of length.
52. Explain Carbon-14 and Tritium dating.
53. How may isotopes be used to eliminate static electricity?
54. How have radiations been used to improve plastics?
55. Why has cold sterilization of foods by radiation been abandoned?
56. Describe the beta current electric cell.
57. Describe the other nuclear electric cells.

VIII LABORATORY OBJECTIVES
FOR
NUCLEAR SCIENCE

1. The student shall indicate to the teacher, orally and manually, operational skills pertinent to correct utilization of the scaler assigned.

   1.1 The student shall indicate on a scaler the operational controls. (*Operational controls* means the off-on switch, high voltage switch, meter zero adjustment knob, high voltage rheostat, voltage indicator, count reset button, calibration switch, and timer reset button.)

   1.2 The student shall, in correct sequence, undertake the operations to prepare the scaler for sample counting.

   1.3 Given a radioactive sample, the student shall determine background activity, count the sample, and convert this count to a true count-per-minute value for that sample, including the standard deviation.

2. Given a new Geiger-Muller tube for the scaler, the student shall count a sample in a regular progression of voltages. The student shall graph this information as counts per minute versus voltage.

   2.1 On the graph described in Objective 2, the student shall indicate the threshold voltage, Geiger-Muller plateau, the area of continuous discharge, and the operating voltage.

3. Given a calibrated radioactive source, the student shall determine its activity on a scaler. From these data, the student shall calculate the efficiency of the scaler. This procedure shall be repeated for each shelf of the sample holder.

4. The student shall make at least 40 one-half minute counts of the sample under identical conditions. From these data, the student shall determine the mean, medium, and most probable count of that sample.

   1.4 From the above data, the student shall calculate the standard deviation of the count.

5. Given a set of radionuclides of high activity, the student shall determine the *dead time* (resolving time) of the scaler.

   5.1 Given an extremely radioactive sample, the student shall obtain a count for that sample. The student shall then, utilizing the scaler dead time, determine mathematically a correct count.

6. By counting a sample at successive intervals of one centimeter, the student shall show, graphically, that the number of counts per minute varies inversely with the square of the distance.

7. Utilizing a beta-emitting radioisotope and the calibrated absorbers, the student shall calculate graphically the half-thickness of the absorber material from data which was obtained.

   7.1 Using lead absorbers with the same radioactive source, the student shall produce and detect *bremsstrahlung* radiation.

8. Using a gamma-emitting radioisotope and the lead absorbers, the student shall, from the data collected, determine the mass absorption coefficient and the absorber half-thickness.

    8.1 From the data obtained under Objectives 7 and 8, the student shall, on a written laboratory report, identify at least two problems pertaining to the construction of biological shields for radiation protection.

9. The student shall record the effects of backscattering of beta particles from data procured by counting the activity of a calibrated source over varying absorber thicknesses.

10. Using data obtained from determination of counts per minute of a stationary sample and cylinders of pure metallic elements of varying atomic weights, the student shall construct a graph of counts per minute versus atomic weight. The student will then be given a cylinder of unknown material. Utilizing the method described above, the student shall determine the atomic weight and the identity of the unknown element.

11. Utilizing a collimated stream of beta particles passing between the poles of an electromagnet, the student shall locate the stream of particles with an end window tube and measure the amount of deflection. From these data the polarity of the electromagnet shall be determined.

12. Utilizing the methods and results of Objectives 7 and 8, the student shall identify the radiations being emitted from an unknown radioactive source.

13. From daily counts of prepared samples of a short-lived isotope the student shall calculate, graphically and mathematically, the half-life and decay constant (lambda value) of the radioisotope.

14. The student shall, in a laboratory situation, separate *normal type, tagged* molecules of differing molecular weights by ascending paper chromatography and identify the rate of flow by means of autoradiographs.

IX LABORATORY EXPERIMENTS AND TECHNIQUES

The fact that most high school laboratories will not have more than one or two scaler-ratemeters available due to their high cost and to the fact that they are not standard equipment will be a major inconvenience, making it necessary to have only a few students using the scaler at any one time.

One solution to the problem is to separate the class into a number of laboratory groups of perhaps three or four students, with each group performing a separate experiment during any one laboratory period. This necessitates a major scheduling task, but it is resolved with a little effort. The teacher can circulate among the groups, giving advice and direction where necessary. It is necessary to duplicate the experimental procedures and to give the proper directions to each group ahead of time. These directions should outline the experimental procedures and include related questions concerning the work in order to attempt to develop further insight concerning the experiment.

It is recommended that a formal written laboratory report be submitted two days following any experiment. This report should include the purpose of the experiment, the procedures, the observations, the conclusions, and the related questions, in that order. The written report gives more reason to the student to make careful manipulations and observations, as well as requiring further thought and study concerning the experiment, resulting in increased learning.

The following are a number of laboratory experiments which may be included in this course of study. The first experiments must necessarily concern the operation of the equipment and the properties of radioisotopes, while the last group may be devoted to the applications of radioisotopes. It should be emphasized that these experiments should be subjected to continuous revision. Many further experiments may be found in the various Atomic Energy Commission booklets or laboratory manuals available. A list of these booklets and manuals is included in Chapter IV. (NOTE: The Atomic Energy Commission is now the U.S. Energy Research and Development Administration).

LABORATORY EXPERIMENTS

A. Experiment 1:

Title - Familiarization With the Characteristics of the Geiger-Muller Counter

Objective -
1. To determine the characteristics of a G-M counter.
2. To determine the slope of the plateau and the operating voltage of the G-M counter.
3. To determine the resolving time of the G-M counter.
4. To prepare a calibrated beta source and measure the G-M counter's efficiency for the source.

B. Experiment 2:

Title - Radiation Counting Statistics

Objective -
1. To demonstrate the statistical variation of background.
2. To demonstrate the statistical variation of decay.
3. To demonstrate the statistical variation caused by sample preparation and sample positioning.

C. Experiment 3:

Title - Radiation Measurement Variables

Objective -
1. To study the geometric counting factors.
2. To study scattering factors.
3. To study self-absorption factors.

D Experiment 4:

Title - Interaction of Radiation With Matter and Identification of Radioisotopes

Objective -
1. To study the interaction of alpha radiation with air.
2. To study the interaction of beta radiation with aluminum absorbers.
3. To study the interaction of gamma radiation with aluminum and lead absorbers.
4. To utilize mass absorption data and half-life data to identify an unknown radioisotope.

E. Experiment 5:

Title - Biological Tracer and Autoradiography

Objective -
1. To study the rate at which phosphorus is absorbed by plant roots and translocated to the leaves using P-32 tracer.
2. To study the resulting distribution of phosphorus in the plant by using autoradiographic techniques.

F. Experiment 6:

Title - Activation Analysis Using a Neutron Howitzer

Objective -
1. To demonstrate the construction and use of a neutron howitzer.
2. To demonstrate the concept of neutron activation.
3. To study the production and subsequent decay of indium-116m.
4. To study the complex activation and decay of silver-108 and silver-110.

G. Experiment 7:

Title - Critical Mass Experiment Using The Pennsylvania State University TRIGA Reactor*

Objective -
1. To study the operation of a nuclear reactor.
2. To study the concepts of neutron multiplication and critical mass.
3. To participate in bringing a reactor to critical conditions.

*Pennsylvania teachers may arrange a one-day class experimental trip by contacting:

Dr. Warren F. Witzig, Chairman
Department of Nuclear Engineering
The Pennsylvania State University
231 Sackett Building
University Park, PA 16802

Possible Projects on Radioisotope Applications

1. The Diffusion of Fe^{59} in the Tissues of the Rat.
2. A study of the Uptake of I^{131} in the Thyroid Gland of the Rat.
3. Fertilizer Uptake in Plants.
4. Effects of X-Radiation on Seed Germination.
5. Production of Mutations by X-Rays.
6. The Incorporation of $C^{14}O_2$ into Sugars by Photosynthesis.
7. Biological Half-Life.
8. A Radioactive Study of Osmosis.
9. The Tagging of Erythrocytes with Fe^{59}.
10. Assimilation of an Isotope in Laboratory Animals.
11. Uptake of P^{32} and S^{35} by Bacteria or Yeast.
12. Sterilization of Drosophila with X-Radiation.
13. Ecological Studies of *normal type tagged* Insects.
14. Skeletal Autoradiography.
15. Translocation of Newly Synthesized Carbohydrates in Plants.
16. Autoradiography of Biological Specimens.
17. The Uptake of Ca^{45} by Bone.
18. Determination of Blood Volume of an Organism by Isotopic Dilution.
19. Any other project you might select, if approved.

SOME ADDITIONAL ACTIVITIES - CHEMICAL APPLICATIONS

A. **Experiments in Nuclear Science,** Second Edition by Chase, Rituper, and Sulcoski:

#45 Electrodeposition

#46 & #47 Separation by Precipitation

#48 Separation by Absorption

#49 Separation by Solvent Extraction

#50 Radiochromatography

#52 Separation by Ion Exchange

#53 Separation by Electrophoresis

#54 Isotope Dilution Analysis

#55 Synthesis of a Labeled Compound

#56 Solubility of Silver Iodide in Ammonia

B. **Radioisotope Experiments for the Chemistry Curriculum**, TID-6374, by Radin (Editor)

G-7 Ion Exchange Separation of Co and Ni

C-1 Determination of Atomic Weights

C-2 Chemistry of Sulfur

C-3 Secular Equilibrium

C-4 Determination of a Solubility Product

C-5 Separation of Ions by Liquid/Liquid Extraction

C-6 Coprecipitation of Calcium and Permanganate with Barium Sulfate

C-7 Determination of Phosphate in a Phosphate Rock by an Isotopic Yield Method

C-8 Determination of the Formation Constant of a Complex Ion

C-9 Determination of Calcium

C-10 Preparation of Sulfanilamide-S-35

C-11 Pre[illegible] of Acetyl-1-C-14 Salicylic Acid

C-1[illegible] [illegible]cation of Amines

C-13 Dynamic Nature of Equilibria

C-14 Exchange between Metals and Ions

C-15 Study of the Phase Diagram of a Three Component System

C-16 The Phenomenon of Absorption

C. **Principles of Radioisotope Methodology**, Third Edition, by Chase and Rabinowitz

10.1 Precipitation

10.2 Coprecipitation

10.3 Solvent Extraction

10.4	Chromatography
10.5	Ion Exchange
10.6	Gas Chromatography
10.7	Distillation
10.8	Electrodeposition
10.9	Electrophoresis
12.1	Solubility Measurements
12.2	Exchange Kinetics
12.3	Isotope Dilution Techniques
12.4	Radiometric Analysis
12.5	Activation Analysis
12.6	Synthesis of Labeled Compounds
12.7	Degradation Methods

SOME ADDITIONAL ACTIVITIES - BIOLOGICAL APPLICATIONS

A. **Experiments in Nuclear Science**, Second Edition, by Chase, Rituper, and Sulcoski

#30 Absorption of Phosphorus by Frogs

#31 Absorption of Phosphorus by Fish

#32 Blood Volume

#33 Cancer in Plants

#34 Effect of Ultraviolet Radiation on Simple Organisms

#35 Effect of Radiation on Mammals

B. **Biology Experiments in Nucleonics**, edited by Kramer and Gemill:

#18 Uptake and Yttrium-90 by Aquatic Animals

#20 Distribution of Radioactivity in Mice

#21 Lung Scanning Agent

#22 Liver Scanning Agent

C. **Tracing Life Processes with Radioisotopes,** NYO-3247-4, by Hulburt:

Distribution of Radiophosphate in Grafted Plants

Absorption of Radiotracers by Planaria

Utilization of Radioactive Elements by the Fresh Water Clam

Absorption of Radioactive Phosphorus by Yeast Cells

Dynamics of Iron Metabolism in Mammals

Studies in Hematology Using Radiochromium

Kinetics of Iodine Metabolism in the Rat

Absorption of Radiophosphorus by Bacterial Species

The Role of Phosphorus in Bacterial Nutrition

Study of Biosynthesis in *Escherichia coli*

Glucose Metabolism in *Escherichia coli*

The Effect of an Antibiotic on Biosynthesis in *Escherichia coli*

D. **Laboratory Experiments with Radioisotopes** by Schenberg

#14 Translocation of Radioactive Phosphorus in Celery Stalks

#16 Translation of Radioactive Phosphorus Upward and Downward in the Geranium Plant via Stem

#17 Removal of Radioactive Phosphorus from Water by Goldfish

#18 Absorption of Radioactive Phosphorus by Yeast

#19 Absorption of Radioactive Phosphorus by Bacteria, Molds, and Drosophila

E. **Principles of Radioisotope Methodology**, Third Edition, by Chase and Rabinowitz

13.1 In-Vitro Measurements (With Sacrifice of Animal)

13.2 Introduction to Metabolic Studies

13.3 In-Vivo and In-Situ Measurements

13.4 Scanning Techniques

13.5 Whole Body Counters (Applied to Measurment of Uptake Rate and Biological Half-life)

13.6 Intermediary Metabolism

13.7 Reaction Rate of Enzyme-Catalyzed Reactions

13.8 Biosynthesis of a Labeled Compound in a Tissue Homogenate

13.9 Biosynthesis of a Compound in a Living Plant

14.1 Effect of Radiation on Enzymes

14.2 Effect of Radiation on Cells

14.3 Somatic Effects of Radiation

14.4 Genetic Effects of Radiation

15.1 Blood Volume (Radio-Iodinated Serum Albumin Method)

15.2 Blood Volume (Sodium Radiochromate Method)

15.3 Red Cell Survival Time (Sodium Radiochromate Method)

15.4 Sequestration of Red Blood Cells (Chromium 51 Scanning Technique)

15.5 Gastro-Intestinal Bleeding

15.6 Thyroid Uptake

15.7 Urinary Excretion of I^{131}

15.8 PBI Conversion Ratio

15.9 Triiodothyronine In-Vitro Uptake Methods

5.10 The Schilling Test For Pernicious Anemia

5.11 Kinetics of Iron Metabolism

5.12 Fat Absorption

5.13 Renal Function

SOME ADDITIONAL ACTIVITIES - INDUSTRIAL APPLICATIONS

A. **Experiments In Nuclear Science**, Second Edition, by Chase, Rituper, and Sulcoski

#58 Strain Gauges

#61 Radiography

#62 Wear Testing

B. **Experiments In Nucleonics**, edited by Kramer and Gemmill:

#18 Gauging

#19 Tracing

#21 Wear Studies

#22 Flow Rate of Liquids

#23 Determination of the Amount of Liquid in a Container

#24 Determination of the Volume of a Container

The following material is merely a preliminary guide in what is believed to be a pioneering effort to introduce a course of this type into the high school curriculum, thus making it available to high ability students who plan to make the sciences their life work. With the production of texts keyed to this type of course, and with the accumulation of new knowledge in this field, the course content will change; some material will undoubtedly be added, while some will just as certainly be deleted in the light of new knowledge.

X PHYSICAL CONSTANTS AND EQUIVALENTS

	Quantity	Symbol	Value
1.	Velocity of Light	C	2.998 X 10^{10} cm sec^{-1}
2.	Avogadro Number	N	6.025 X 10^{23} molecules $mole^{-1}$
3.	Ångstrom Unit	Å	10^{-8} cm
4.	Planck's Constant	h	6.625 X 10^{-27} erg-sec
5.	Curie	C	3.7 X 10^{10} disintegrations sec^{-1}
6.	Millicurie	mC	3.7 X 10^{7} disintegrations sec^{-1}
7.	Microcurie	μC	3.7 X 10^{4} disintegrations sec^{-1}
8.	Micro micro Curie	μμC	3.7 X 10^{-2} disintegrations sec^{-1}
9.	Mass of an Electron	e^-, β	9.11 X 10^{-28} gm or 5.5 X 10^{-4} amu
10.	Mass of an Alpha Particle	${}^{4}_{2}a$	6.6 X 10^{-24} gm or 4.002777 amu
11.	Mass of a Neutron	${}_{o}n^{1}$	1.67 X 10^{-24} or 1.00898Z amu
12.	Mass of a Proton	${}^{1}_{1}p$	1.67 X 10^{-24} or 1.008142 amu
13.	Atomic Mass Unit	amu	1.65 X 10^{-24} gm or 931 MeV
14.	Roentgen	R	83 ergs gm^{-1} or 1 esu cc^{-1} (air) or 1.6 X 10^{2} ion pairs / gm
15.	Roentgen Equivalent Man	REM	83 ergs/gm (soft tissue)
16.	Barn	σ	10^{-24} cm^{2}
17.	Coulomb	Q	3 X 10^{9} esu

Quantity	Symbol	Value
18. Nuclear Density	-	10^{14} gm/cc or 10^{8} Tons/cc
19. Nuclear Size	-	10^{-12} to 10^{-13} cm
20. Median Lethal Dose	LD50	400 R
21. Million Electron Volts	MeV	10^{6} eV or 1.6 X 10^{6} ergs
22. Electron Volt	eV	1.6 X 10^{-19} joule or 1.6 X 10^{-12} erg
23. Year	-	5.25 X 10^{5} min. 3.15 X 10^{7} sec
24. Day	-	1.44 X 10^{3} min. or 8.64 X 10^{4} sec
25. Lambda	λ	1 microliter (1 X 10^{-6} l) (1.0 μl)

CHARACTERISTICS OF COMMON RADIOISOTOPES

Radioisotope	Half-Life	Beta Energy (MeV)	Gamma Energies (MeV)
Barium-137	2.6 minutes	None	2.6
Calcium-45	160 days	0.254	None
Carbon-14	5,600 years	0.155	None
Cesium-137	30 years	0.514, 1.17	None
Chlorine-36	3.1X10^{5} years	0.714	None
Cobalt-60	5.2 years	0.306	1.17, 1.33
Copper-64	12.8 hours	0.571 (β^-), 0.657 (β^+)	1.34
Gold-198	2.7 days	0.29, 0.97	0.411 to 1.09
Hydrogen-3	12.26 years	0.01795	None
Indium-113	100 minutes	None	0.393

Radioisotope	Half-Life	Beta Energy (MeV)	Gamma Energies (MeV)
Iodine-131	8.05 days	0.250 to 0.815	0.080 to 0.722
Iron-59	2.9 days	0.271, 0.462, 1.560	0.191, 1.098, 1.289
Nickel-63	80 years	0.067	None
Phosphorus-32	14.5 days	1.701	None
Potassium-42	12.5 hours	2.04, 3.58	1.51
Sodium-22	2.6 years	0.54 (β^+)	1.28
Strontium-90	28 years	0.61	None
Sulfur-35	87 days	0.167	None
Thallium-204	2.5 years	0.764	None
Tin-113	115 days	ec	None
Uranium-238	4.5 X 10^9 years	σ (4.19) β^{mme}	0.048
Yttrium-90	64 hours	2.26	None
Zinc-65	245 days	0.325 (β^+)	1.12

XI THE GREEK ALPHABET

Greek Letters cap.	l.c.	English Equivalent	English Name	English Pronunciation
Α	α	a	alpha	al-fa
Β	β	b	beta	bā-ta
Γ	γ	g	gamma	gam-ma
Δ	δ	d	delta	del-ta
Ε	ε	e	epsilon	ep-si-lon
Ζ	ζ	z (dz)	zeta	zā-ta
Η	η	ā	eta	āta
Θ	θ	th	theta	thā-ta
Ι	ι	ē	iota	ī-ō-ta
Κ	κ	k	kappa	kap-pa
Λ	λ	l	lambda	lam-da
Μ	μ	m	mu	mew
Ν	ν	n	nu	new
Ξ	ξ	x (ks)	xi	zī
Ο	ο	o	omicron	ōm-i-cron
Π	π	p	pi	pī
Ρ	ρ	r	rho	rōw
Σ	σ	s	sigma	sig-ma
Τ	τ	t	tau	taw
Υ	υ	y (u)	upsilon	up-si-lon
Φ	φ	f (ph)	phi	fī
Χ	χ	ch	chi	kī
Ψ	ψ	ps	psi	sī
Ω	ω	ō	omega	ō-may-ga

XII FUNDAMENTAL PARTICLES

Category	Name	Symbol	Antiparticle	Rest mass	Baryon number	Lepton number	Strangeness number	Half-life (sec)
Baryons	omega hyperon	Ω^-	Ω^+	3280	+1	0	-3	$\sim 10^{-10}$
	xi hyperon	Ξ^- Ξ^0	$\overline{\Xi^-}$ $\overline{\Xi^0}$	2584 2572	+1 +1	0 0	-2 -2	1.2×10^{-10} 2.1×10^{-10}
	sigma hyperon	Σ^- Σ^0 Σ^+	$\overline{\Sigma^-}$ $\overline{\Sigma^0}$ $\overline{\Sigma^+}$	2343 2333 2327	+1 +1 +1	0 0 0	-1 -1 -1	1.1×10^{-10} $\sim 10^{-20}$ 5.5×10^{-11}
	lambda hyperon	Λ^0	$\overline{\Lambda^0}$	2183	+1	0	-1	1.8×10^{-10}
	neutron	n	$\overline{n}$	1839	+1	0	0	700
	proton	p	$\overline{p}$	1836	+1	0	0	stable
Mesons	eta meson	η^0	$\overline{\eta^0}$	1074	0	0	0	$\sim 10^{-20}$
	kappa meson (kaon)	K^+ K^0	$\overline{K^+}$ $\overline{K^0}$	966 975	0 0	0 0	+1 +1	8.5×10^{-7} 6.4×10^{-9} 4.0×10^{-8}
	pi meson (pion)	π^+ π^0	$\overline{\pi^-}$ $\overline{\pi^0}$	273 264	0 0	0 0	0 0	1.8×10^{-8} 1.3×10^{-16}
leptons	mu meson (muon)	μ^-	μ^+	207	0	+1	-1	1.5×10^{-6}
	electron	e^-	e^+	1	0	+1	0	stable
	neutrino$_\mu$	ν_μ	$\overline{\nu_\mu}$	0	0	+1	0	stable
	neutrino$_e$	ν_e	$\overline{\nu_e}$	0	0	+1	0	stable
bosons	photon	γ	γ	0	0	0	0	stable
	graviton	g	g	0	0	0	0	stable

Note: The baryon, lepton, and strangeness numbers are those of the particle named at the left. In each case, the antiparticle has numbers with the same magnitude but with opposite charge. The half-life is that of the particle at the left. Antiparticles have half-lives that are considerably different from those of the corresponding particles.

XIII EXPONENTIAL FUNCTIONS

X	e^x	e^{-x}
0.00	1.000	2.000
0.10	1.104	0.905
0.20	1.221	0.819
0.30	1.350	0.741
0.40	1.492	0.670
0.50	1.649	0.607
0.60	1.822	0.549
0.70	2.014	0.497
0.80	2.226	0.449
0.90	2.460	0.407
1.00	2.718	0.368
1.50	4.482	0.223
2.00	7.389	0.135
2.50	12.182	0.082
3.00	20.086	0.050
3.50	33.115	0.030
4.00	54.598	0.018
4.50	90.017	0.011
5.00	148.41	0.007
6.00	403.43	0.002
7.00	1096.6	0.001
8.00	2981.0	0.0003
9.00	8103.1	0.0001
10.00	22026	0.00004

NOTE: $3^{-x} \cong 1-x$ for small values of x (i.e., $x < .40$)

XIV TEACHING AIDS

Films

The films listed may be procured on a loan basis from:

USERDA Film Library
Box 62
Oak Ridge, Tenn. 37830

Title	Time (Min)
A IS FOR ATOM	15
LIVING WITH RADIATION	28
THE ATOM AND YOU	16
MEDICINE	10
AGRICULTURE, INDUSTRY AND POWER	20
ATOMIC FURNACES	20
ATOM SMASHING	12.5
THE ATOMIC GREENHOUSE	12.5
TAGGING THE ATOM	12.5
THE ATOMIC ZOO	12.5
THE ATOMIC PHARMACY	12.5
THE ATOMIC ALCHEMIST	12.5
THE MASTER SLAVE	12.5
THE RIDDLE OF PHOTOSYNTHESIS	12.6
ATOMS FOR HEALTH	12.5
NUCLEAR REACTORS FOR RESEARCH	15
UNLOCKING THE ATOM	11.5
OPERATION IVY	28
OPERATION SANDSTONE	18
OPERATIONS CROSSROADS	27
THE MAGNETIC BOTTLE	12.5

Other films are listed at the conclusion of each unit of the course of study. The films are obtained from:

Beatrice Martinelli
Public Information Service
U.S. Energy Research and Development Administration
New York Operations Office
376 Hudson Street
New York, NY 10014

Telephone: 212-489-1234

Film Catalogues may be obtained from:

Audio-Visual Branch
Division of Public Information
U.S. Energy Research and Development Administration
Washington, D C 20545

A series of filmstrips for nuclear science has been prepared by:

Radiation Science Seminar
John W. Sulcoski, Director
80 N. Washington Street
Wilkes-Barre, PA 18701

These shall be distributed at a later date, but any teacher desiring to consider their use may obtain information by writing to Mr. Sulcoski.

A catalogue with complete film descriptons and ordering information for the films listed at the end of the units is available from ERDA. These are free loan films; you are responsible for return postage. Write to:

ERDA - Technical Information Center
Box 62
Oak Ridge, TN 37830

Booklets

The following titles are booklets that may be obtained from ERDA for a nominal fee. They are available from:

ERDA - Technical Information Center
Box 62
Oak Ridge, TN 37830

The following titles in the ERDA booklet program are scheduled to go out of print and will *not be reissued.* While the supply lasts, these booklets are available free in classroom quantities.

Accelerators (1969)
Atoms at the Science Fair (1964)
Atomic Power Safety (1964)
Atoms, Nature, and Man (1966)
Cryogenics: The Uncommon Cold (1967)
Electricity and Man (1972)
Fallout from Nuclear Tests (1966)
Lasers (1968)
Microstructure of Matter (1967)
The Natural Radiation Environment (1968)
Nondestructive Testing (1965)
Nuclear Energy for Desalting (1967)
Nuclear Propulsion for Space, (1971)
Nuclear Reactors for Space Power (1971)
Radioactive Wastes (1969)
Radioisotopes and Life Processes (1967)

Radioisotopes in Industry (1965)
Radioisotopes in Medicine (1966)
Synthetic Transuranium Elements (1964)
Spectroscopy (1968)
U.S. Atomic Energy Commission (1973)
Whole Body Counters (1967)

The following booklets are available at these rates:

1 booklet	$0.45
2-9 booklets	0.35 each
10-30 booklets	0.30 each
31 or more booklets	0.20 each

If you would like to purchase any of these booklets, please use the order form obtainable from ERDA.

Solar, Geothermal, and Advanced Energy Systems

IB-403 **Controlled Nuclear Fusion** by Samuel Glasstone, 50 pp. 1974. Research on a vast source of power for the future.

IB-405 **The Elusive Neutrino** by Jeremy Bernstein, 78 pp. 1969. Discovery of and research involving this important elementary particle of matter.

IB-701 **Geothermal Energy** by William W. Eaton. 42 pp. 1975. Basic information about the use of geothermal energy to provide electrical power and the developments in technology that will be needed to use it more effectively for the benefit of humanity.

IB-416 **Inner Space: The Structure of the Atom** by Samuel Glasstone. 99 pp. 1972. History and present-day knowledge of the principles and concepts of atomic structure.

IB-801 **Solar Energy** by William W. Eaton. 45 pp. 1976. Basic information about the use of solar energy to provide electrical power and the developments in technology that will be needed to use it more effectively for the benefit of humanity.

IB-105 **The Genetic Effects of Radiation** by Isaac Asimov and Theodosius Dobzhansky. 49 pp. 1966. How radiation affects reproductive cells and succeeding generations.

IB-414 **Nature's Invisible Rays** by Joseph Kastner. 44 pp. 1973. Current research involving the radiation that has existed on earth since the beginning of time.

IB-204 **Nuclear Power and the Environment** by Joseph M. Dukert. 87 pp. 1976. How nuclear reactors affect the environment.

IB-412 **Space Radiation** by William Corliss. 58 pp. 1968. Radiations from beyond our atmosphere.

IB-109 **Your Body and Radiation** by Norman A. Frigerio. 78 pp. 1967. Ionizing radiation effects on living tissues.

Energy

IB-021 **Creating Energy Choices for the Future: A Summary of the National Plan for Energy Research, Development, and Demonstration.** 33 pp. 1975. A brief description of ERDA's national energy plan.

IB-020 **The Economics of America's Energy Future** by Henry Simmons. 61 pp. 1975. An overview of the economics of this country's energy resources.

IB-1002 **Energy Technology** by William W. Eaton. 60 pp. 1975. General information about what our energy resources are, how we use them, what we are doing to improve methods of storing and transmitting energy, and what can be done to plan for intelligent use of energy in the future.

Conservation

IB-404 **Direct Conversion of Energy** by William R. Corliss, 34 pp. 1964. Producing electricity without generators.

IB-1001 **Energy Storage** by William W. Eaton, 35 pp. 1975. Basic information about present and proposed methods of improving energy storage to meet constantly increasing demands from the public for more power.

Nuclear Energy

IB-009 **Atomic Energy and Your World** by Samuel Glasstone and S. Joe Thomas, 57 pp. 1970. How atomic energy is produced and how its peaceful uses are helping to build a better world.

IB-515 **Atoms on the Move: Transportation of Radioactive Materials** by Joseph M. Dukert. 53 pp. 1975. Describes types of materials, methods of packaging, transport vehicles, safety precautions, and transportation regulations.

IB-002 **A Bibliography of Basic Books on Atomic Energy**. 58 pp. 1974. A reading list of 172 commercially available books.

IB-503 **The First Reactor**. 46 pp. 1967. Dramatic story of the first controlled nuclear chain reaction.

IB-514 **High-Level Radioactive Waste: Safe Storage and Ultimate Disposal** by Joseph M. Dukert. 23 pp. 1975. Delineates the methods of managing high-level radioactive waste from commercial nuclear reactors.

IB-505 **Nuclear Power Plants** by Ray L. Lyerly and Walter Mitchell, III. 54 pp. 1973. Their economics, future, and how they are used today to generate electricity.

IB-507 **Nuclear Reactors** by John F. Hogerton. 54 pp. 1970. A broad survey of types and uses.

IB-006 **Nuclear Terms: A Glossary**. 80 pp. 1967. Definitions of 400 terms.

IB-019 **Stamps Tell the Story of Nuclear Energy** by Joseph A. Angelo, Jr. 100 pp. 1975. Commemorative postage stamps from all over the world are used to illustrate the story of nuclear energy. The book includes spaces for stamps throughout the text, album pages for additional stamps, and a list of nuclear stamps.

IB-014, O-15, & O-16 **Worlds Within Worlds: The Story of Nuclear Energy Volumes 1, 2, and 3** by Isaac Asimov, 172 pp. 1972. A history of nuclear energy from the ancient Greeks to the present.

Miscellaneous

IB-303 **The Atomic Fingerprint: Neutron Activation Analysis** by Bernard Keisch. 56 pp. 1972. Identifying traces of elements by their atomic fingerprints.

IB-010 **Atomic Pioneers-Book 1: From Ancient Greece to the 19th Century** by Ray and Roselyn Hiebert. 65 pp. 1970. The stories of 25 men (5 B.C. to 1850) and their contributions to atomic science. This is the first of a four-booklet set of biographies up to and including present-day scientists.

IB-011 **Atomic Pioneers-Book 1: From the Mid-19th to the Early 20th Century** by Ray and Roselyn Hiebert. 94 pp. 1971. The stories of 26 men and women and their contributions to atomic science. This is the second of a four-booklet set of biographies up to and including present-day scientists.

IB-012 **Atomic Pioneers-Book 3: From the Late 19th to the Mid-20th Century** by Ray and Roselyn Hiebert. 99 pp. 1973. The stories of 24 men and 1 woman and their contributions to atomic science. This is the third of a four-booklet set of biographies up to and including present-day scientists.

IB-004 **Computers** by William R. Corliss. 56 pp. 1974. How electronic brains work.

IB-018 **The First Book of Information Science** by Joseph Becker. 91 pp. 1974. Information science is the study of how human beings communicate with each other. It is concerned with discovering better ways to get the right information quickly to the person who needs it, and with finding information later, once it is stored in libraries and other centers of information. This booklet is a primer on information science.

IB-310 **Lost Worlds: Nuclear Science and Archeology** by Bernard Keisch. 54 pp. 1973. A fictional mystery story is used to explain nuclear techniques and instruments that can determine the age of archeological artifacts. This is a sequel to **The Mysterious Box, Nuclear Science and Art.**

IB-309 **The Mysterious Box: Nuclear Science and Art** by Bernard Keisch. 39 pp. 1970. A fictional mystery story involving lost treasure is used to explain the nuclear techniques and instruments that can determine the age of oil paintings.

IB-415 **The Mystery of Matter** by William G. Pollard. 58 pp. 1970. The fascinating search for the key to the structure of matter.

IB-017 **Teleoperators: Man's Machine Partners** by William R. Corliss. 47 pp. 1972. Describes machines that add to humans strength, their reach, and their ability to work in hostil environments.

Pamphlets

Copies of the following pamphlets are available free to individuals and in reasonable quantities for classroom and group use.

If you would like copies of any of these pamphlets, please write to:

ERDA - Technical Information Center

Creating Energy Choices for the Future: Highlights from the National Plan for Energy Research, Development, and Demonstration. 12 pp. 1975.
The Economics of Nuclear Power. 8 pp. 1976.
Fusion. 9 pp. 1974.
Geothermal Energy. 13 pp. 1976.
Heated Water from Power Plants. 6 pp. 1974.
Oil Shale. 8 pp. 1974.
Shipping of Nuclear Wastes. 9 pp. 1974.
Solar Energy. 11 pp. 1975.

The following pamphlets are available for a nominal fee from:

Atomic Industrial Forum Inc.
Public Affairs and Information Program
7101 Wisconsin Avenue
Washington, D.C. 20014

Insuring Nuclear Risks
The Savings with Nuclear Energy
Managing Nuclear Waste
How Nuclear Plants Work

Catalogue

Catalogue of Publications & Services
American Nuclear Society
299 East Ogden Avenue
Hinsdale, Ill. 60521
Phone: 312/325-1991

Filmstrips

A series of filmstrips for nuclear science has been prepared by:

Radiation Science Seminar
John W. Sulcoski, Director
80 N. Washington Street
Wilkes-Barre, PA 18701

(These filmstrips are also distributed by:
The Nucleus
P.O. Box R
Oak Ridge, TN 37830)

Games

A game for teaching radioactive decay and the chart of the nuclides is available from:

Relativistics
P.O. Box 1064
Greensburg, PA 15601

Video Tapes

Worcester Polytechnic Institute offers a series of 18 video tapes entitled **The Nuclear Power Controversy**. A summary of the tapes and ordering information may be obtained by writing to:

Prof. L. C. Wilbur
Director
Nuclear Reactor Facility
Worcester Polytechnic Institute
Worcester, Mass. 01609

The Allegheny Educational Broadcast Council has produced a series of 15-20 minute programs entitled **Nuclear Science**. These are broadcasted by WPSX, Clearfield, PA during the school year.

Other Publications

Nuclear Canada
Canadian Nuclear Society
65 Queen Street West
Toronto, Ontario M5H ZM5
Canada

ERDA News — Free
Office of Public Affairs
Energy Research and Development Administration
Washington, D.C. 20545

Energy International — $20.00
Circulation Department
500 Howard Street
San Francisco, CA 74105

CHARTS

1. Periodic Table of the Elements, Cenco
2. General Electric Chart of the Nuclides, Knolls Atomic Power Laboratory
3. Iostope Chart, Dr. te Neues & Co., Kempen, W. Germany
4. Spectrum Analysis Chart, Cenco

XV METHODS OF INSTRUCTION

The methods used in any course will, of course, depend upon the teacher.

Some subject areas, such as particle accelerators, may be best covered by lecture and class discussion, due to the complexity of the available texts. Glasstone is recommended as a general reference, since its coverage is rather extensive, and the literary style is quite readable.

The use of study guides keyed to the basic text has been shown to work well. These question sheets guide the student's reading and study, making it possible to delete extraneous material and to emphasize that which is considered important. An assignment on these guides will serve as a preparation for lecture and discussion, insuring as much as possible homogeneity of preparation and information throughout the class. These guide sheets plus the student's class notes provide excellent review facilities at the end of a unit or at the end of the year.

Care must be exercised that the students are not limited to the study guide questions, but that they be required to perform extra reading assignments and to solve extra problem sets, thus attempting to insure a broader coverage of the subject matter than that afforded by the guide alone.

TEXTS

1. Harvey, Bernard G. **An Introduction to Nuclear Physics and Chemistry**. 2nd Ed. 1969. Prentice-Hall, Englewood Cliffs, NJ
2. Seaborg, Glenn T. & Corliss, William R. **Man and Atom: Shaping A New World Through Nuclear Technology**. 1971. Dutton
3. Thompson, William E., Jr. **Your Future in Nuclear Energy Fields**. 1971. Arco. paperback
4. Jungk, Robert **Brighter Than A Thousand Suns: A Personal History of the Atomic Scientists**. 1970. Harcourt, Brace and Jonanovich - paperback
5. Meyer. , Leo **Nuclear Power In Industry**. 2nd Ed. Grade 11 and up. 1974. American Technical Society.

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Gerhart, Friedlander, et al. **Nuclear and Radiochemistry**. 2nd Ed., Wiley Publishing Co., 605 3rd Ave., New York, NY 10016 (c) 1964.

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Lapp, Andrews, **Nuclear Radiation Physics**. (c) 1972, Prentice-Hall, Englewood Cliffs, NJ 07632.

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IAEA, **Radioisotopes in the Physical Sciences and Industry**. 3 Vol. (c) 1962.

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Fremlin, J. H., **Applications of Nuclear Physics**. (c) 1970. Hart Publishing Co., 15 West 4th St., New York, NY 10012

Fravenfelder, Henley, **Subatomic Physics**. (c) 1974. Prentice-Hall, Englewood Cliffs, NJ 07632

Curie, Marie, **Radioactive Substances**. 1971-Reprint, Greenwood Press Inc., 51 Riverside Ave., Westport, CT 06880

Mladjenovic, **Radioisotope and Radiation Physics: An Introduction**. Academic Press, 111 5th Ave., New York, NY 10003. (c) 1973

Graetzer, Anderson, **Discovery of Nuclear Fission**. (c) 1971, Van Nostrand Reinhold Educational Publishing Inc., 450 W. 33rd St., New York, NY 10003 - paperback

Harvard Project Physics Course, Holt, Reinhart, Winston. Text: Units IV [illegible] V [illegible] 1971. Supplements A and B

PDE, ERDA, **Environmental Impact of Electrical Power Generation: Nuclear and Fossil**. US G.P.O. Washington, DC 20402

U.S. Department of Health, Education & Welfare, **Radiological Health Handbook**. US G.P.O. 1960

ANS., **Nuclear Power and the Environment: Questions and Answers**. 224 East Ogden Ave., Hinsdale, Il 60521 (c) 1976-Reprint.

APPENDIX

PART 19

NOTICES, INSTRUCTIONS, AND REPORTS TO WORKERS; INSPECTIONS

Sec.
19.1 Purpose.
19.2 Scope.
19.3 Definitions.
19.4 Interpretations.
19.5 Communications.
19.11 Posting of notices to workers.
19.12 Instruction to workers.
19.13 Notifications and reports to individuals.
19.14 Presence of representatives of licensees and workers during inspections.
19.15 Consultation with workers during inspections.
19.16 Requests by workers for inspections.
19.17 Inspection not warranted; informal review.
19.30 Violations.
19.31 Application for exemptions.
19.32 Discrimination prohibited.

AUTHORITY: Secs. 53, 63, 81, 103, 104, 161, Pub. L. 83-703, 68 Stat. 930, 933, 935, 936, 937, 948, as amended (42 U.S.C. 2073, 2093, 2111, 2133, 2134, 2201); Sec. 201, Pub. L. 93-438, 88 Stat. 1242 (42 U.S.C. 5841)

§ 19.1 Purpose.

The regulations in this part establish requirements for notices, instructions, and reports by licensees to individuals participating in licensed activities, and options available to such individuals in connection with Commission inspections of licensees to ascertain compliance with the provisions of the Atomic Energy Act of 1954, as amended, Title II of the Energy Reorganization Act of 1974, and regulations, orders, and licenses thereunder regarding radiological working conditions.

§ 19.2 Scope.

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed by the Nuclear Regulatory Commission pursuant to the regulations in Parts 30 through 35, 40, or 70 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter.

§ 19.3 Definitions.

As used in this part:

(a) "Act" means the Atomic Energy Act of 1954, (68 Stat. 919) including any amendments thereto;

(b) "Commission" means the United States Nuclear Regulatory Commission;

(c) "Worker" means an individual engaged in activities licensed by the Commission and controlled by a licensee, but does not include the licensee.

(d) "License" means a license issued under the regulations in Parts 30 through 35, 40, or 70 of this chapter, including licenses to operate a production or utilization facility pursuant to Part 50 of this chapter. "Licensee" means the holder of such a license.

(e) "Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

§ 19.4 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

§ 19.5 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 1717 H Street, NW., Washington, D.C.; or at 7920 Norfolk Avenue, Bethesda, Maryland.

§ 19.11 Posting of notices to workers.

(a) Each licensee shall post current copies of the following documents: (1) The regulations in this part and in Part 20 of this chapter; (2) the license, license conditions, or documents incorporated into a license by reference, and amendments thereto; (3) the operating procedures applicable to licensed activities; (4) any notice of violation involving radiological working conditions, proposed imposition of civil penalty, or order issued pursuant to Subpart B of Part 2 of this chapter, and any response from the licensee.

(b) If posting of a document specified in paragraph (a) (1), (2) or (3) of this section is not practicable, the licensee may post a notice which describes the document and states where it may be examined.

(c) Form NRC-3, "Notice to Employees", shall be posted by each licensee wherever individuals work in or frequent any portion of a restricted area.

NOTE: Copies of Form NRC-3 may be obtained by writing to the Director of the appropriate U.S. Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix "D", Part 20 of this chapter, or the Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

(d) Documents, notices, or forms posted pursuant to this section shall appear in a sufficient number of places to permit individuals engaged in licensed activities to observe them on the way to or from any particular licensed activity location to which the document applies, shall be conspicuous, and shall be replaced if defaced or altered.

(e) Commission documents posted pursuant to paragraph (a)(4) of this section shall be posted within 2 working days after receipt of the documents from the Commission; the licensee's response, if any, shall be posted within 2 working days after dispatch by the licensee. Such documents shall remain posted for a minimum of 5 working days or until action correcting the violation has been completed, whichever is later.

§ 19.12 Instructions to workers.

All individuals working in or frequenting any portion of a restricted area shall be kept informed of the storage, transfer, or use of radioactive materials or of radiation in such portions of the restricted area; shall be instructed in the health protection problems associated with exposure to such radioactive materials or radiation, in precautions or procedures to minimize exposure, and in the purposes and functions of protective devices employed; shall be instructed in, and instructed to observe, to the extent within the worker's control, the applicable provisions of Commission regulations and licenses for the protection of personnel from exposures to radiation or radioactive materials occurring in such areas; shall be instructed of their responsibility to report promptly to the licensee any condition which may lead to or cause a violation of Commission regulations and licenses or unnecessary exposure to radiation or to radioactive material; shall be instructed in the appropriate response to warnings made in the event of any unusual occurrence or malfunction that may involve exposure to radiation or radioactive material; and shall be advised as to the radiation exposure reports which workers may request pursuant to § 19.13. The extent of these instructions shall be commensurate with potential radiological health protection problems in the restricted area.

§ 19.13 Notifications and reports to individuals.

(a) Radiation exposure data for an individual, and the results of any measurements, analyses, and calculations of radioactive material deposited or retained in the body of an individual, shall be reported to the individual as specified in this section. The information reported shall include data and results obtained pursuant to Commission regulations, orders or license conditions, as shown in records maintained by the licensee pursuant to Commission regulations. Each notification and report shall: be in writing; include appropriate identifying data such as the name of the licensee, the name of the individual, the individual's social security number; include the individual's exposure information; and contain the following statement:

> This report is furnished to you under the provisions of the Nuclear Regulatory Commission regulation 10 CFR Part 19. You should preserve this report for further reference.

38 FR 22217

(b) At the request of any worker each licensee shall advise such worker annually of the worker's exposure to radiation or radioactive material as shown in records maintained by the licensee pursuant to § 20.401(a) and (c).

(c) At the request of a worker formerly engaged in licensed activities controlled by the licensee, each licensee shall furnish to the worker a report of the worker's exposure to radiation or radioactive material. Such report shall be furnished within 30 days from the time the request is made, or within 30 days after the exposure of the individual has been determined by the licensee, whichever is later; shall cover, within the period of time specified in the request, each calendar quarter in which the worker's activities involved exposure to radiation from radioactive materials licensed by the Commission; and shall include the dates and locations of licensed activities in which the worker participated during this period.

(d) When a licensee is required pursuant to § 20.405 or § 20.408 of this chapter to report to the Commission any exposure of an individual to radiation or radioactive material the licensee shall also provide the individual a report on exposure data included therein. Such report shall be transmitted at a time not later than the transmittal to the Commission.

§ 19.14 Presence of representatives of licensees and workers during inspections.

(a) Each licensee shall afford to the Commission at all reasonable times opportunity to inspect materials, activities, facilities, premises, and records pursuant to the regulations in this chapter.

(b) During an inspection, Commission inspectors may consult privately with workers as specified in § 19.15. The licensee or licensee's representative may accompany Commission inspectors during other phases of an inspection.

(c) If, at the time of inspection, an individual has been authorized by the workers to represent them during Commission inspections, the licensee shall notify the inspectors of such authorization and shall give the workers' representative an opportunity to accompany the inspectors during the inspection of physical working conditions.

(d) Each workers' representative shall be routinely engaged in licensed activities under control of the licensee and shall have received instructions as specified in § 19.12.

(e) Different representatives of licensees and workers may accompany the inspectors during different phases of an inspection if there is no resulting interference with the conduct of the inspection. However, only one workers' representative at a time may accompany the inspectors.

38 FR 22217

(f) With the approval of the licensee and the workers' representative an individual who is not routinely engaged in licensed activities under control of the licensee, for example, a consultant to the licensee or to the workers' representative, shall be afforded the opportunity to accompany Commission inspectors during the inspection of physical working conditions.

(g) Notwithstanding the other provisions of this section, Commission inspectors are authorized to refuse to permit accompaniment by any individual who deliberately interferes with a fair and orderly inspection. With regard to areas containing information classified by an agency of the U.S. Government in the interest of national security, an individual who accompanies an inspector may have access to such information only if authorized to do so. With regard to any area containing proprietary information, the workers' representative for that area shall be an individual previously authorized by the licensee to enter that area.

§ 19.15 Consultation with workers during inspections.

(a) Commission inspectors may consult privately with workers concerning matters of occupational radiation protection and other matters related to applicable provisions of Commission regulations and licenses to the extent the inspectors deem necessary for the conduct of an effective and thorough inspection.

(b) During the course of an inspection any worker may bring privately to the attention of the inspectors, either orally or in writing, any past or present condition which he has reason to believe may have contributed to or caused any violation of the act, the regulations in this chapter, or license condition, or any unnecessary exposure of an individual to radiation from licensed radioactive material under the licensee's control. Any such notice in writing shall comply with the requirements of § 19.16(a).

(c) The provisions of paragraph (b) of this section shall not be interpreted as authorization to disregard instructions pursuant to § 19.12.

§ 19.16 Requests by workers for inspections.

(a) Any worker or representative of workers who believes that a violation of the Act, the regulations in this chapter, or license conditions exists or has occurred in license activities with regard to radiological working conditions in which the worker is engaged, may request an inspection by giving notice of the alleged violation to the Director of Inspection and Enforcement, to the Director of the appropriate Commission Regional Office, or to Commission inspectors. Any such notice shall be in writing, shall set forth the specific grounds for the notice, and shall be signed by the worker or representative of workers. A copy shall be provided the licensee by the Director of Inspection and Enforcement, Regional Office Director, or the inspector no later than at the time of inspection except that, upon the request of the worker giving such notice, his name and the name of individuals referred to therein shall not appear in such copy or on any record published, released, or made available by the Commission, except for good cause shown.

38 FR 22217

(b) If, upon receipt of such notice, the Director of Inspection and Enforcement or Regional Office Director determines that the complaint meets the requirements set forth in paragraph (a) of this section, and that there are reasonable grounds to believe that the alleged violation exists or has occurred, he shall cause an inspection to be made as soon as practicable, to determine if such alleged violation exists or has occurred. Inspections pursuant to this section need not be limited to matters referred to in the complaint.

(c) No licensee shall discharge or in any manner discriminate against any worker because such worker has filed any complaint or instituted or caused to be instituted any proceeding under the regulations in this chapter or has testified or is about to testify in any such proceeding or because of the exercise by such worker on behalf of himself or others of any option afforded by this part.

§ 19.17 Inspections not warranted; informal review.

(a) If the Director of Inspection and Enforcement or of the appropriate Regional Office determines, with respect to a complaint under § 19.16, that an inspection is not warranted because there are no reasonable grounds to believe that a violation exists or has occurred, he shall notify the complainant in writing of such determination. The complainant may obtain review of such determination by submitting a written statement of posi-

38 FR 22217

tion with the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, who will provide the licensee with a copy of such statement by certified mail, excluding, at the request of the complainant, the name of the complainant. The licensee may submit an opposing written statement of position with the Executive Director for Operations who will provide the complainant with a copy of such statement by certified mail. Upon the request of the complainant, the Executive Director for Operations or his designee may hold an informal conference in which the complainant and the licensee may orally present their views. An informal conference may also be held at the request of the licensee, but disclosure of the identity of the complainant will be made only following receipt of written authorization from the complainant. After considering all written and oral views presented, the Executive Director for Operations shall affirm, modify, or reverse the determination of the Director of Inspection and Enforcement or of the appropriate Regional Office and furnish the complainant and the licensee a written notification of his decision and the reason therefor.

(b) If the Director of Inspection and Enforcement or of the appropriate Regional Office determines that an inspection is not warranted because the requirements of § 19.16(a) have not been met, he shall notify the complainant in writing of such determination. Such determination shall be without prejudice to the filing of a new complaint meeting the requirements of § 19.16(a).

40 FR 8774

§ 19.30 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Act or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder.

38 FR 22217

A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act or any rule, regulation, or order issued thereunder, or any term, condition or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

§ 19.31 Application for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

40 FR 8774

§ 19.32 Discrimination prohibited.

No person shall on the ground of sex be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity licensed by the Nuclear Regulatory Commission. This provision will be enforced through agency provisions and rules similar to those already established, with respect to racial and other discrimination, under title VI of the Civil Rights Act of 1964. This remedy is not exclusive, however, and will not prejudice or cut off any other legal remedies available to a discriminatee.

UNITED STATES NUCLEAR REGULATORY COMMISSION
RULES and REGULATIONS
TITLE 10, CHAPTER 1, CODE OF FEDERAL REGULATIONS—ENERGY

PART 20
STANDARDS FOR PROTECTION AGAINST RADIATION

GENERAL PROVISIONS

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20.402 Reports of theft or loss of licensed material.
20.403 Notifications of incidents.
20.404 [Reserved]
20.405 Reports of overexposures and excessive levels and concentrations.
20.406 [Reserved]
20.407 Personnel exposure and monitoring reports.
20.408 Reports of personnel exposure on termination of employment or work.
20.409 Notifications and reports to individuals.

EXCEPTIONS AND ADDITIONAL REQUIREMENTS

20.501 Applications for exemptions.
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20.601 Violations

Appendix A—[Reserved]
Appendix B—Concentrations in air and water above natural background.
Appendix C.
Appendix D—United States Nuclear Regulatory Commission Inspection and Enforcement Regional Offices.

AUTHORITY: The provisions of this Part 20 issued under secs. 53, 63, 65, 81, 103, 104, 161, 68 Stat. 930, 933, 935, 936, 937, 948, as amended; 42 U.S.C. 2073, 2093, 2095, 2111, 2133, 2134, 2201. For the purposes of sec. 223, 68 Stat. 958, as amended; 42 U.S.C. 2273, §§20.401-20.409, issued under sec. 161 o., 68 Stat. 950, as amended; 42 U.S.C. 2201 (o). Secs. 202, 206, Pub. L. 93-438, 88 Stat. 1244, 1246 (42 U.S.C. 5842, 5846).

§ 20.1 Purpose.

(a) The regulations in this part establish standards for protection against radiation hazards arising out of activities under licenses issued by the Nuclear Regulatory Commission and are issued pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974.

40 FR 8774

(b) The use of radioactive material or other sources of radiation not licensed by the Commission is not subject to the regulations in this part. However, it is the purpose of the regulations in this part to control the possession, use, and transfer of licensed material by any licensee in such a manner that exposure to such material and to radiation from such material, when added to exposures to unlicensed radioactive material and to other unlicensed sources of radiation in the possession of the licensee, and to radiation therefrom, does not exceed the standards of radiation protection prescribed in the regulations in this part.

25 FR 10914

(c) In accordance with recommendations of the Federal Radiation Council, approved by the President, persons engaged in activities under licenses issued by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974 should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas, as low as is reasonably achievable. The term "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.

40 FR 58847

§ 20.2 Scope.

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed pursuant to the regulations in Parts 30 through 35, 40, or 70 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter.

40 FR 8774

§ 20.3 Definitions.

(a) As used in this part:

(1) "Act" means the Atomic Energy Act of 1954 (68 Stat. 919) including any amendments thereto;

(2) "Airborne radioactive material" means any radioactive material dispersed in the air in the form of dusts, fumes, mists, vapors, or gases;

(3) "Byproduct material" means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material;

(4) "Calendar quarter" means not less than 12 consecutive weeks nor more than 14 consecutive weeks. The first calendar quarter of each year shall begin in January and subsequent calendar quarters shall be such that no day is included in more than one calendar quarter or omitted from inclusion within a calendar quarter. No licensee shall change the method observed by him of determining calendar quarters except at the beginning of a calendar year.

40 FR 42557

(5) "Commission" means the Nuclear Regulatory Commission or its duly authorized representatives;

(6) "Government agency" means any executive department, commission, independent establishment, corporation, wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the Government;

(7) "Individual" means any human being;

(8) "Licensed material" means source material, special nuclear material, or by-product material received, possessed, used, or transferred under a general or specific license issued by the Commission pursuant to the regulations in this chapter;

(9) "License" means a license issued under the regulations in Part 30, 40, or 70 of this chapter. "Licensee" means the holder of such license;

(10) "Occupational dose" includes exposure of an individual to radiation (i) in a restricted area; or (ii) in the course of employment in which the individual's duties involve exposure to radiation; provided, that "occupational dose" shall not be deemed to include any exposure of an individual to radiation for the purpose of medical diagnosis or medical therapy of such individual.

25 FR 10914

(11) "Person" means (i) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than the Commission or the Administration (except that the Administration shall be considered a person within the meaning of the regulations in this part to the extent that its facilities and activities are subject to the licensing and related regulatory authority of the Commission pursuant to section 202 of the Energy Reorganization Act of 1974 (88 Stat. 1244)), any State, any foreign government or nation or any political subdivision of any such government or nation, or other entity; and (ii) any legal successor, representative, agent, or agency of the foregoing.

40 FR 8774

(12) "Radiation" means any or all of the following: alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but not sound or radio waves, or visible, infrared, or ultraviolet light;

(13) "Radioactive material" includes any such material whether or not subject to licensing control by the Commission;

25 FR 10914

(14) "Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area;

25 FR 13952

(15) "Source material" means (i) uranium or thorium, or any combination thereof, in any physical or chemical form; or (ii) ores which contain by weight one-twentieth of one percent (0.05%) or more of a. uranium, b. thorium or c. any combination thereof. Source material does not include special nuclear material.

[27 FR 5905]

(16) "Special nuclear material" means (i) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include source material; or (ii) any material artificially enriched by any of the foregoing but does not include source material;

25 FR 10914

(17) "Unrestricted area" means any area access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

[25 FR 13952]

(18) "Administration" means the Energy Research and Development Administration or its duly authorized representatives.

[40 FR 8774]

(b) Definitions of certain other words and phrases as used in this part are set forth in other sections, including:

(1) "Airborne radioactivity area" defined in § 20.203;

(2) "Radiation area" and "high radiation area" defined in § 20.202;

(3) "Personnel monitoring equipment" defined in § 20.202;

(4) "Survey" defined in § 20.201;

(5) Units of measurement of dose (rad, rem) defined in § 20.4;

(6) Units of measurement of radioactivity defined in § 20.5.

§ 20.4 Units of radiation dose.

(a) "Dose," as used in this part, is the quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. When the regulations in this part specify a dose during a period of time, the dose means the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units as used in this part are set forth in paragraphs (b) and (c) of this section.

(b) The rad, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue. (One millirad (mrad) = 0.001 rad.)

(c) The rem, as used in this part, is a measure of the dose of any ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-rays. (One millirem (mrem) = 0.001 rem.) The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions of irradiation. For the purpose of the regulations in this part, any of the following is considered to be equivalent to a dose of one rem:

(1) A dose of 1 r due to X— or gamma radiation;

(2) A dose of 1 rad due to X—, gamma, or beta radiation;

(3) A dose of 0.1 rad due to neutrons or high energy protons;

(4) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye;

If it is more convenient to measure the neutron flux, or equivalent, than to determine the neutron dose in rads, as provided in subparagraph (3) of this paragraph, one rem of neutron radiation may, for purposes of the regulations in this part, be assumed to be equivalent to 14 million neutrons per square centimeter incident upon the body; or, if there exists sufficient information to estimate with reasonable accuracy the approximate distribution in energy of the neutrons, the incident number of neutrons per square centimeter equivalent to one rem may be estimated from the following table:

NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (Mev)	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm²)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm² per sec.)
Thermal	970×10^6	670
0.0001	720×10^6	500
0.005	820×10^6	570
0.02	400×10^6	280
0.1	120×10^6	80
0.5	43×10^6	30
1.0	26×10^6	18
2.5	29×10^6	20
5.0	26×10^6	18
7.5	24×10^6	17
10	24×10^6	17
10 to 30	14×10^6	10

(d) For determining exposures to X or gamma rays up to 3 Mev, the dose limits specified in §§ 20.101 to 20.104, inclusive, may be assumed to be equivalent to the "air dose". For the purpose of this part "air dose" means that the dose is measured by a properly calibrated appropriate instrument in air at or near the body surface in the region of highest dosage rate.

25 FR 10914

§ 20.5 Units of radioactivity.

(a) Radioactivity is commonly, and for purposes of the regulations in this part shall be, measured in terms of disintegrations per unit time or in curies. One curie = 3.7×10^{10} disintegrations per second (dps) = 2.2×10^{12} disintegrations per minute (dpm). Commonly used submultiples of the curie are the millicurie and the microcurie:

(1) One millicurie (mCi)[1] = 0.001 curie (Ci)[1] = 3.7×10^7 dps.

(2) One microcurie (μCi)[1] = 0.000001 curie = 3.7×10^4 dps.

38 FR 29314

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[1] Wherever possible, the appropriate units should be written out as "curie(s)," "millicurie(s)," or "microcurie(s)," and the abbreviations should not be used.

(b) [Deleted 40 FR 50704.]

(c) [Deleted 39 FR 23990.]

§ 20.6 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

25 FR 10914

§ 20.7 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C.; or at 7920 Norfolk Avenue, Bethesda, Maryland.

40 FR 8774

** PERMISSIBLE DOSES, LEVELS, AND CONCENTRATIONS

§ 20.101 Exposure of individuals to radiation in restricted areas.

(a) Except as provided in paragraph (b) of this section, no licensee shall possess, use, or transfer licensed material in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of the limits specified in the following table:

	Rems per calendar quarter
1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1¼
2. Hands and forearms; feet and ankles	18¾
3. Skin of whole body	7½

(b) A licensee may permit an individual in a restricted area to receive a dose to the whole body greater than that permitted under paragraph (a) of this section, provided:

(1) During any calendar quarter the dose to the whole body from radioactive material and other sources of radiation in the licensee's possession shall not exceed 3 rems; and

(2) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N–18) rems where "N" equals the individual's age in years at his last birthday; and

(3) The licensee has determined the individual's accumulated occupational dose to the whole body on Form NRC-4, or on a clear and legible record containing all the information required in that form; and has otherwise complied with the requirements of § 20.102. As used in paragraph (b), "Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye.

25 FR 10914

§ 20.102 Determination of accumulated dose.

(a) This section contains requirements which must be satisfied by licensees who propose, pursuant to paragraph (b) of § 20.101, to permit individuals in a restricted area to receive exposure to radiation in excess of the limits specified in paragraph (a) of § 20.101.

(b) Before permitting any individual in a restricted area to receive exposure to radiation in excess of the limits specified in paragraph (a) of § 20.101, each licensee shall:

(1) Obtain a certificate on Form NRC-4, or on a clear and legible record containing all the information required in that form, signed by the individual showing each period of time after the individual attained the age of 18 in which the individual received an occupational dose of radiation; and

(2) Calculate on Form NRC-4 in accordance with the instructions appearing therein, or on a clear and legible record containing all the information required in that form, the previously accumulated occupational dose received by the individual and the additional dose allowed for that individual under § 20.101(b).

(c)(1) In the preparation of Form NRC-4, or a clear and legible record containing all the information required in that form, the licensee shall make a reasonable effort to obtain reports of the individual's previously accumulated occupational dose. For each period for which the licensee obtains such reports, the licensee shall use the dose shown in the report in preparing the form. In any case where a licensee is unable to obtain reports of the individual's occupational dose for a previous complete calendar quarter, it shall be assumed that the individual has received the occupational dose specified in whichever of the following columns apply:

Part of body	Column 1 Assumed exposure in rems for calendar quarters prior to Jan. 1, 1961	Column 2 Assumed exposure in rems for calendar quarters beginning on or after Jan. 1, 1961
Whole body, gonads, active blood-forming organs, head and trunk, lens of eye.	3¾	1¼

(2) The licensee shall retain and preserve records used in preparing Form NRC-4. If calculation of the individual's accumulated occupational dose for all periods prior to January 1, 1961 yields a result higher than the applicable accumulated dose value for the individual as of that date, as specified in paragraph (b) of § 20.101, the excess may be disregarded.

25 FR 10914

§ 20.103 Exposure of individuals to concentrations of radioactive material in restricted areas.

(a) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual in a restricted area to be exposed to airborne radioactive material possessed by the licensee in an average concentration in excess of the limits specified in Appendix B, Table I, of this part. "Expose" as used in this section means that the individual is present in an airborne concentration. No allowance shall be made for the use of protective clothing or equipment, or particle size, except as authorized by the Commission pursuant to paragraph (c) of this section.

(b) The limits given in Appendix B, Table I, of this part are based upon exposure to the concentrations specified for forty hours in any period of seven consecutive days. In any such period where the number of hours of exposure is less than forty, the limits specified in the table may be increased proportionately. In any such period where the number of hours of exposure is greater than forty, the limits specified in the table shall be decreased proportionately.

(c)(1) Except as authorized by the Commission pursuant to this paragraph, no allowance shall be made for particle size or the use of protective clothing or equipment in determining whether an individual is exposed to an airborne concentration in excess of the limits specified in Appendix B, Table I.

(2) The Commission may authorize a licensee to expose an individual in a restricted area to airborne concentrations in excess of the limits specified in Appendix B, Table I, upon receipt of an application demonstrating that the concentration is composed in whole or in part of particles of such size that such particles are not respirable; and that the individual will not inhale the concentrations in excess of the limits established in Appendix B, Table I. Each application under this subparagraph shall include an analysis of particle sizes in the concentrations; and a description

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[8] The duration of sample collection and the duration of measurement should be sufficiently short compared to the time between collection and measurement, as not to have a statistically significant effect upon the results.

** Amended 36 FR 1466.

NOTE: Amendments made by 40 FR 50704 become effective 1/29/76.

of the methods used in determining the particle sizes.

(3) The Commission may authorize a licensee to expose an individual in a restricted area to airborne concentrations in excess of the limits specified in Appendix B, Table I, upon receipt of an application demonstrating that the individual will wear appropriate protective equipment and that the individual will not inhale, ingest or absorb quantities of radioactive material in excess of those which might otherwise be permitted under this part for employees in restricted areas during a 40-hour week. Each application under this subparagraph shall contain the following information:

(i) A description of the protective equipment to be employed, including the efficiency of the equipment for the material involved;

(ii) Procedures for the fitting, maintenance and cleaning of the protective equipment; and

(iii) Procedures governing the use of the protective equipment, including supervisory procedures and length of time the equipment will be used by the individuals in each work week. The proposed periods for use of the equipment by any individual should not be of such duration as would discourage observance by the individual of the proposed procedures; and

(iv) The average concentrations present in the areas occupied by employees.

25 FR 10914

§ 20.104 Exposure of minors.

No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area who is under 18 years of age, to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of 10 percent of the limits specified in the table in paragraph (a) of § 20.101.

(b) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area, who is under 18 years of age to be exposed to airborne radioactive material possessed by the licensee in an average concentration in excess of the limits specified in Appendix B, Table II of this part. For purposes of this paragraph, concentrations may be averaged over periods not greater than a week.

(c) The provisions of paragraph (c) of § 20.103, shall apply to exposures subject to paragraph (b) of this section.

§ 20.105 Permissible levels of radiation in unrestricted areas.

(a) There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as to anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrates that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem.

(b) Except as authorized by the Commission pursuant to paragraph (a) of this section, no licensee shall possess, use or transfer licensed material in such a manner as to create in any unrestricted area from radioactive material and other sources of radiation in his possession:

(1) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of two millirems in any one hour, or

(2) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 100 millirems in any seven consecutive days.

25 FR 10914

§ 20.106 Radioactivity in effluents to unrestricted areas.

(a) A licensee shall not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations which exceed the limits specified in Appendix "B", Table II of this part, except as authorized pursuant to § 20.302 or paragraph (b) of this section. For purposes of this section concentrations may be averaged over a period not greater than one year.

(b) An application for a license or amendment may include proposed limits higher than those specified in paragraph (a) of this section. The Commission will approve the proposed limits if the applicant demonstrates:

(1) That the applicant has made a reasonable effort to minimize the radioactivity contained in effluents to unrestricted areas; and

(2) That it is not likely that radioactive material discharged in the effluent would result in the exposure of an individual to concentrations of radioactive material in air or water exceeding the limits specified in Appendix "B", Table II of this part.

29 FR 14434

(c) An application for higher limits pursuant to paragraph (b) of this section shall include information demonstrating that the applicant has made a reasonable effort to minimize the radioactivity discharged in effluents to unrestricted areas, and shall include, as pertinent:

(1) Information as to flow rates, total volume of effluent, peak concentration of each radionuclide in the effluent, and concentration of each radionuclide in the effluent averaged over a period of one year at the point where the effluent leaves a stack, tube, pipe, or similar conduit;

(2) A description of the properties of the effluents, including:

(i) chemical composition;

(ii) physical characteristics, including suspended solids content in liquid effluents, and nature of gas or aerosol for air effluents;

(iii) the hydrogen ion concentrations (p^H) of liquid effluents; and

(iv) the size range of particulates in effluents released into air.

(3) A description of the anticipated human occupancy in the unrestricted area where the highest concentration of radioactive material from the effluent is expected, and, in the case of a river or stream, a description of water uses downstream from the point of release of the effluent.

(4) Information as to the highest concentration of each radionuclide in an unrestricted area, including anticipated concentrations averaged over a period of one year:

(i) In air at any point of human occupancy; or

(ii) In water at points of use downstream from the point of release of the effluent.

(5) The background concentration of radionuclides in the receiving river or stream prior to the release of liquid effluent.

(6) A description of the environmental monitoring equipment, including sensitivity of the system, and procedures and calculations to determine concentrations of radionuclides in the unrestricted area and possible reconcentrations of radionuclides.

(7) A description of the waste treatment facilities and procedures used to reduce the concentration of radionuclides in effluents prior to their release.

(d) For the purposes of this section the concentration limits in Appendix "B", Table II of this part shall apply at the boundary of the restricted area. The concentration of radioactive material discharged through a stack, pipe or similar conduit may be determined with respect to the point where the material leaves the conduit. If the conduit discharges within the restricted area, the concentration at the boundary may be determined by applying appropriate factors for dilution, dispersion, or decay between the point of discharge and the boundary.

29 FR 14434

(e) In addition to limiting concentrations in effluent streams, the Commission may limit quantities of radioactive materials released in air or water during a specified period of time if it appears that the daily intake of radioactive material from air, water, or food by a suitable sample of an exposed population group, averaged over a period not exceeding one year, would otherwise exceed the daily intake resulting from continuous exposure to air or water containing one-third the concentration of radioactive materials specified in Appendix "B", Table II of this part.

(f) The provisions of this section do not apply to disposal of radioactive material into sanitary sewerage systems, which is governed by § 20.303

§ 20.107 Medical diagnosis and therapy.

Nothing in the regulations in this part shall be interpreted as limiting the intentional exposure of patients to radiation for the purpose of medical diagnosis or medical therapy.

25 FR 10914

§ 20.108 Orders requiring furnishing of bio-assay services.

Where necessary or desirable in order to aid in determining the extent of an individual's exposure to concentrations of radioactive material, the Commission may incorporate appropriate provisions in any license, directing the licensee to make available to the individual appropriate bio-assay services and to furnish a copy of the reports of such services to the Commission.

PRECAUTIONARY PROCEDURES

§ 20.201 Surveys.

(a) As used in the regulations in this part, "survey" means an evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions. When appropriate, such evaluation includes a physical survey of the location of materials and equipment, and measurements of levels of radiation or concentrations of radioactive material present.

(b) Each licensee shall make or cause to be made such surveys as may be necessary for him to comply with the regulations in this part.

§ 20.202 Personnel monitoring.

(a) Each licensee shall supply appropriate personnel monitoring equipment to, and shall require the use of such equipment by:

(1) Each individual who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the applicable value specified in paragraph (a) of § 20.101.

25 FR 10914

(2) Each individual under 18 years of age who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 5 percent of the applicable value specified in paragraph (a) of § 20.101.

(3) Each individual who enters a high radiation area.

(b) As used in this part,

(1) "Personnel monitoring equipment" means devices designed to be worn or carried by an individual for the purpose of measuring the dose received (e. g., film badges, pocket chambers, pocket dosimeters, film rings, etc.);

(2) "Radiation area" means any area, accessible to personnel, in which there exists radiation, originating in whole or in part within licensed material, at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirems;

(3) "High radiation area" means any area, accessible to personnel, in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem.

35 FR 5033

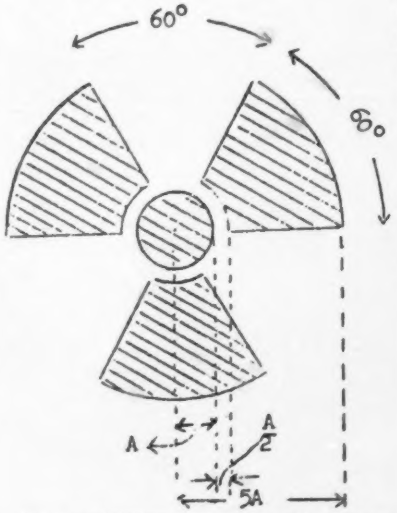
35 FR 5033

§ 20.203 Caution signs, labels, signals, and controls.

(a) *General.* (1) Except as otherwise authorized by the Commission, symbols prescribed by this section shall use the conventional radiation caution colors (magenta or purple on yellow background). The symbol prescribed by this section is the conventional three-bladed design:

RADIATION SYMBOL

1. Cross-hatched area is to be magenta or purple.
2. Background is to be yellow.



(2) In addition to the contents of signs and labels prescribed in this section, licensees may provide on or near such signs and labels any additional information which may be appropriate in aiding individuals to minimize exposure to radiation or to radioactive material.

(b) *Radiation areas.* Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
RADIATION AREA

(c) *High radiation areas.* (1) Each high radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
HIGH RADIATION AREA

(2) Each entrance or access point to a high radiation area shall be:

(i) Equipped with a control device which shall cause the level of radiation to be reduced below that at which an individual might receive a dose of 100 millirems in 1 hour upon entry into the area; or

(ii) Equipped with a control device which shall energize a conspicuous visible or audible alarm signal in such a manner that the individual entering the high radiation area and the licensee or a supervisor of the activity are made aware of the entry; or

(iii) Maintained locked except during periods when access to the area is required, with positive control over each individual entry.

(3) The controls required by subparagraph (2) of this paragraph shall be established in such a way that no individual will be prevented from leaving a high radiation area.

(4) In the case of a high radiation area established for a period of 30 days or less, direct surveillance to prevent unauthorized entry may be substituted for the controls required by subparagraph (2) of this paragraph.

(5) Any licensee, or applicant for a license, may apply to the Commission for approval of methods not included in subparagraphs (2) and (4) of this paragraph for controlling access to high radiation areas. The Commission will approve the proposed alternatives if the licensee or applicant demonstrates that the alternative methods of control will prevent unauthorized entry into a high radiation area, and that the requirement of subparagraph (3) of this paragraph is met.

35 FR 5033

(d) *Airborne radioactivity areas.* (1) As used in the regulations in this part, "airborne radioactivity area" means (i) any room, enclosure, or operating area in which airborne radioactive materials, composed wholly or partly of licensed material, exist in concentrations in excess of the amounts specified in Appendix B, Table I, Column 1 of this part; or (ii) any room, enclosure, or operating area in which airborne radioactive material composed wholly or partly of licensed material exists in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amounts specified in Appendix B, Table I, Column 1 of this part.

(2) Each airborne radioactivity area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
AIRBORNE RADIOACTIVITY AREA

(e) *Additional requirements.* (1) Each area or room in which licensed material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in an amount exceeding 10 times the quantity of such material specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
RADIOACTIVE MATERIAL(S)

(2) Each area or room in which natural uranium or thorium is used or stored in an amount exceeding one-hundred times the quantity specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
RADIOACTIVE MATERIAL(S)

(f) *Containers.* (1) Except as provided in subparagraph (2) of this paragraph, each container of licensed material shall bear a durable, clearly visible label identifying the radioactive contents.

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[1] Or "Danger."

(2) A label required pursuant to subparagraph (1) of this paragraph shall bear the radiation caution symbol and the words "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL". It shall also provide sufficient information[1] to permit individuals handling or using the containers, or working in the vicinity thereof, to take precautions to avoid or minimize exposures.

(3) Notwithstanding the provisions of subparagraph (1) of this paragraph, labeling is not required:

(i) For containers that do not contain licensed materials in quantities greater than the applicable quantities listed in Appendix C of this part.

(ii) For containers containing only natural uranium or thorium in quantities no greater than 10 times the applicable quantities listed in Appendix C of this part.

(iii) For containers that do not contain licensed materials in concentrations greater than the applicable concentrations listed in Column 2, Table I, Appendix B of this part.

(iv) For containers when they are attended by an individual who takes the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established by the regulations in this part.

(v) For containers when they are in transport and packaged and labeled in accordance with regulations of the * Department of Transportation.

(vi) For containers which are accessible[2] only to individuals authorized to handle or use them, or to work in the vicinity thereof, provided that the contents are identified to such individuals by a readily available written record.

(vii) For manufacturing or process equipment, such as nuclear reactors, reactor components, piping, and tanks.

§ 20.204 Same: exceptions.

Notwithstanding the provisions of § 20.203,

(a) A room or area is not required to be posted with a caution sign because of the presence of a sealed source provided the radiation level twelve inches from the surface of the source container or housing does not exceed five millirem per hour.

(b) Rooms or other areas in hospitals are not required to be posted with caution signs, and control of entrance or access thereto pursuant to § 20.203(c) is not required, because of the presence of patients containing byproduct material provided that there are personnel in attendance who will take the precautions necessary to prevent the exposure of any individual to radiation or radioactive material in excess of the limits established in the regulations in this part.

(c) Caution signs are not required to be posted at areas or rooms containing radioactive materials for periods of less than eight hours provided that (1) the materials are constantly attended during such periods by an individual who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established in the regulations in this part and; (2) such area or room is subject to the licensee's control.

(d) A room or other area is not required to be posted with a caution sign, and control is not required for each entrance or access point to a room or other area which is a high radiation area solely because of the presence of radioactive materials prepared for transport and packaged and labeled in accordance with regulations of the Department of Transportation.

§ 20.205 Procedures for picking up, receiving, and opening packages.

(a) (1) Each licensee who expects to receive a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section shall:

(i) If the package is to be delivered to the licensee's facility by the carrier, make arrangements to receive the package when it is offered for delivery by the carrier; or

(ii) If the package is to be picked up by the licensee at the carrier's terminal, make arrangements to receive notification from the carrier of the arrival of the package, at the time of arrival.

(2) Each licensee who picks up a package of radioactive material from a carrier's terminal shall pick up the package expeditiously upon receipt of notification from the carrier of its arrival.

(b) (1) Each licensee, upon receipt of a package of radioactive material, shall monitor the external surfaces of the package for radioactive contamination caused by leakage of the radioactive contents, except:

(i) Packages containing no more than the exempt quantity specified in the table in this paragraph;

(ii) Packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125;

(iii) Packages containing only radioactive material as gases or in special form;

(iv) Packages containing only radioactive material in other than liquid form (including Mo-99/Tc-99m generators) and not exceeding the Type A quantity limit specified in the table in this paragraph; and

(v) Packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries.

The monitoring shall be performed as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or eighteen hours if received after normal working hours.

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify the final delivering carrier and, by telephone and telegraph, mailgram, or facsimile,† the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group[1]	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
I	.01	0.001
II	0.1	0.050
III	1	3
IV	1	20
V	1	20
VI	1	1000
VII	25,000	1000
Special Form	1	20

(c) (1) Each licensee, upon receipt of a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section, other than those transported by exclusive use vehicle, shall monitor the radiation levels external to the package. The package shall be monitored as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or 18 hours if received after normal working hours.

(2) If radiation levels are found on the external surface of the package in excess of 200 millirem per hour, or at three feet from the external surface of the package in excess of 10 millirem per hour, the licensee shall immediately notify by telephone and telegraph, mailgram, or facsimile, the director of the appropriate NRC Regional Office listed in Appendix D, and the final delivering carrier.

(d) Each licensee shall establish and maintain procedures for safely opening packages in which licensed material is received, and shall assure that such procedures are followed and that due consideration is given to special instructions for the type of package being opened.

§ 20.206 Instruction of personnel.

Instructions required for individuals working in or frequenting any portion of a restricted area are specified in § 19.12 of this chapter.

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[1] As appropriate, the information will include radiation levels, kinds of material, estimate of activity, date for which activity is estimated, mass enrichment, etc.

[2] For example, containers in locations such as water-filled canals, storage vaults, or hot cells.

* Amended 34 FR 19546.

[1] The definitions of "transport group" and "special form" are specified in § 71.4 of this chapter.

†Amended 41 FR 16445.

40 FR 26679

§ 20.207 Storage and control of licensed materials in unrestricted areas.

(a) Licensed materials stored in an unrestricted area shall be secured from unauthorized removal from the place of storage.

(b) Licensed materials in an unrestricted area and not in storage shall be tended under the constant surveillance and immediate control of the licensee.

25 FR 10914

WASTE DISPOSAL

§ 20.301 General requirement.

No licensee shall dispose of licensed material except:

(a) By transfer to an authorized recipient as provided in the regulations in Part 30, 40, or 70 of this chapter, whichever may be applicable; or

(b) As authorized pursuant to § 20.302; or

(c) As provided in § 20.303 or § 20.304, applicable respectively to the disposal of licensed material by release into sanitary sewerage systems or burial in soil, or in § 20.106 (Radioactivity in Effluents to Unrestricted Areas).

§ 20.302 Method for obtaining approval of proposed disposal procedures.

*(a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.

26 FR 352

*(b) The Commission will not approve any application for a license to receive licensed material from other persons for disposal on land not owned by the Federal government or by a State government.

36 FR 23138

(c) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal.

25 FR 10914

§ 20.303 Disposal by release into sanitary sewerage systems.

No licensee shall discharge licensed material into a sanitary sewerage system unless:

(a) It is readily soluble or dispersible in water; and

(b) The quantity of any licensed or other radioactive material released into the system by the licensee in any one day does not exceed the larger of subparagraphs (1) or (2) of this paragraph:

(1) The quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in Appendix B, Table I, Column 2 of this part; or

(2) Ten times the quantity of such material specified in Appendix C of this part; and

(c) The quantity of any licensed or other radioactive material released in any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an average concentration exceeding the limits specified in Appendix B, Table I, Column 2 of this part; and

(d) The gross quantity of licensed and other radioactive material released into the sewerage system by the licensee does not exceed one curie per year.

Excreta from individuals undergoing medical diagnosis or therapy with radioactive material shall be exempt from any limitations contained in this section.

25 FR 10914

§ 20.304 Disposal by burial in soil.

No licensee shall dispose of licensed material by burial in soil unless:

(a) The total quantity of licensed and other radioactive materials buried at any one location and time does not exceed, at the time of burial, 1,000 times the amount specified in Appendix C of this part; and

(b) Burial is at a minimum depth of four feet; and

(c) Successive burials are separated by distances of at least six feet and not more than 12 burials are made in any year.

§ 20.305 Treatment or disposal by incineration.

No licensee shall treat or dispose of licensed material by incineration except as specifically approved by the Commission pursuant to §§ 20.106(b) and 20.302.

RECORDS, REPORTS, AND NOTIFICATION

§ 20.401 Records of surveys, radiation monitoring, and disposal.

(a) Each licensee shall maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required under § 20.202 of the regulations in this part. Such records shall be kept on Form NRC-5, in accordance with the instructions contained in that form or on clear and legible records containing all the information required by Form NRC-5. The doses entered on the forms or records shall be for periods of time not exceeding one calendar quarter.

39 FR 17972

(b) Each licensee shall maintain records in the same units used in this part, showing the results of surveys required by § 20.201(b), monitoring required by §§ 20.205(b) and 20.205(c), and disposals made under §§ 20.302, 20.303, and 20.304.

35 FR 6810

(c) Records of individual exposure to radiation and to radioactive material which must be maintained pursuant to the provisions of paragraph (a) of this section and records of bio-assays, including results of whole body counting examinations, made pursuant to § 20.108 shall be preserved indefinitely or until the Commission authorizes their disposal. Records which must be maintained pursuant to this part may be maintained in the form of microfilms.

34 FR 7500

§ 20.402 Reports of theft or loss of licensed material.

(a) Each licensee shall report by telephone and telegraph, mailgram, or facsimile,† to the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D, immediately after its occurrence becomes known to the licensee, any loss or theft of licensed material in such quantities and under such circumstances that it appears to the licensee that a substantial hazard may result to persons in unrestricted areas.

41 FR 16445

(b) Each licensee who is required to make a report pursuant to paragraph (a) of this section shall, within thirty (30) days after he learns of the loss or theft, make a report in writing to the appropriate NRC Regional Office listed in Appendix D with copies to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, setting forth the following information:

34 FR 7500

(1) A description of the licensed material involved, including kind, quantity, chemical, and physical form;

(2) A description of the circumstances under which the loss or theft occurred;

(3) A statement of disposition or probable disposition of the licensed material involved;

(4) Radiation exposures to individuals, circumstances under which the exposures occurred, and the extent of possible hazard to persons in unrestricted areas;

(5) Actions which have been taken, or will be taken, to recover the material; and

(6) Procedures or measures which have been or will be adopted to prevent a recurrence of the loss or theft of licensed material.

(c) Subsequent to filing the written report the licensee shall also report any substantive additional information on the loss or theft which becomes available to the licensee, within 30 days after he learns of such information.

(d) Any report filed with the Commission pursuant to this section shall be so prepared that names of individuals who may have received exposure to radiation are stated in a separate part of the report.

41 FR 16445

§ 20.403 Notifications of incidents.

(a) *Immediate notification.* Each licensee shall immediately notify by telephone and telegraph, mailgram, or facsimile, the Director of the appropriate NRC Regional Office listed in Appendix

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*Redesignated 36 FR 23138.

†Amended 41 FR 16445.

D of any incident involving byproduct, source, or special nuclear material possessed by him and which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 25 rems or more of radiation; exposure of the skin of the whole body of any individual of 150 rems or more of radiation; or exposure of the feet, ankles, hands or forearms of any individual to 375 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limits specified for such materials in Appendix B, Table II; or

(3) A loss of one working week or more of the operation of any facilities affected; or

(4) Damage to property in excess of $100 000.

(b) *Twenty-four hour notification.* Each licensee shall within 24 hours notify by telephone and telegraph, mailgram, or facsimile, the Director of the appropriate NRC Regional Office listed in Appendix D of any incident involving licensed material possessed by him and which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 5 rems or more of radiation; exposure of the skin of the whole body of any individual to 30 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms to 75 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 500 times the limits specified for such materials in Appendix B, Table II; or

(3) A loss of one day or more of the operation of any facilities affected; or

(4) Damage to property in excess of $1,000.

(c) Any report filed with the Commission pursuant to this section shall be prepared so that names of individuals who have received exposure to radiation will be stated in a separate part of the report.

§ 20.404 [Deleted 38 FR 22220.]

§ 20.405 Reports of overexposures and excessive levels and concentrations.

(a) In addition to any notification required by § 20.403, each licensee shall make a report in writing within thirty (30) days to the appropriate NRC Regional Office listed in Appendix D with copies to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, of:

(1) each exposure of an individual to radiation or concentrations of radioactive material in excess of any applicable limit in this part or in the licensee's license; (2) any incident for which notification is required by § 20.403; and (3) levels of radiation or concentrations of radioactive material (not involving excessive exposure of any individual) in an unrestricted area in excess of ten times any applicable limit set forth in this part or in the licensee's license.

Each report required under this paragraph shall describe the extent of exposure of persons to radiation or to radioactive material, including estimates of each individual's exposure as required by paragraph (b) of this section; levels of radiation and concentrations of radioactive material involved; the cause of the exposure, levels or concentrations; and corrective steps taken or planned to assure against a recurrence.

(b) Any report filed with the Commission pursuant to this section shall include for each individual exposed the name, social security number, and date of birth; and an estimate of the individual's exposure. The report shall be prepared so that this information is stated in a separate part of the report.

(c) [Deleted 38 FR 22220.]

§ 20.406 [Deleted 38 FR 22220.]

§ 20.407 Personnel exposure and monitoring reports.

(a) This section applies to each person licensed by the Commission or the Atomic Energy Commission to:

(1) Operate a nuclear reactor designed to produce electrical or heat energy pursuant to § 50.21(b) or § 50.22 of this chapter or a testing facility as defined in § 50.2(r) of this chapter;

(2) Possess or use byproduct material for purposes of radiography pursuant to Parts 30 and 34 of this chapter;

(3) Possess or use at any one time, for purposes of fuel processing, fabrication, or reprocessing, special nuclear material in a quantity exceeding 5,000 grams of contained uranium-235, uranium-233, or plutonium or any combination thereof pursuant to Part 70 of this chapter; or

(4) Possess or use at any one time, for processing or manufacturing for distribution pursuant to Part 30, 32, or 33 of this chapter, byproduct material in quantities exceeding anyone of the following quantities:

Radionuclide[1]	*Quantity in curies*
Cesium-137	1
Cobalt-60	1
Gold-198	100
Iodine-131	1
Iridium-192	10
Krypton-85	1,000
Promethium-147	10
Technetium-99m	1,000

(b) Each person described in paragraph (a) of this section shall, within the first quarter of each calendar year, submit to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555,† the following reports, applicable to the described licensed activities covering the preceding calendar year:[2]

(1) A report of either (i) the total number of individuals for whom personnel monitoring was required under §§ 20.202(a) or 34.33(a) of this chapter during the calendar year, or (ii) the total number of individuals for whom personnel monitoring was provided during the calendar year; *Provided*, that such total includes at least the number of individuals required to be reported under paragraph (b)(1)(i) of this section. The report shall indicate whether it is submitted in accordance with paragraph (b)(1)(i) or (ii) of this section.

(2) A statistical summary report of the personnel monitoring information recorded by the licensee for individuals for whom personnel monitoring was either required or provided, as described in § 20.407(b)(1), indicating the number of individuals whose total whole body exposure recorded during the previous calendar year was in each of the following estimated exposure ranges:

Estimated Whole Body Exposure Range (Rems)[3]	*Number of individuals in each range*
No measurable exposure	
Measurable exposure less than 0.1	
0.1 to 0.25	
0.25 to 0.5	
0.5 to 0.75	
0.75 to 1	
1 to 2	
2 to 3	
3 to 4	
4 to 5	
5 to 6	
6 to 7	
7 to 8	
8 to 9	
9 to 10	
10 to 11	
11 to 12	
12+	

The low exposure range data are required in order to obtain better information about the exposures actually recorded. This section does not require improved measurements.

§ 20.408 Reports of personnel exposure on termination of employment or work.

When an individual terminates employment with a licensee subject to § 20.407, or an individual assigned to work in such a licensee's facility, but not employed by the licensee, completes his work assignment in the licensee's facility, the licensee shall furnish* to the Director of Inspection and Enforcement,† U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, a report of the individual's exposure to radiation and radioactive material, incurred during the period of employment or work assignment in the licensee's facility, containing information recorded by the licensee pursuant to §§ 20.401(a) and 20.108. Such report shall be furnished within 30 days after the exposure of the individual has been determined by the licensee or 90 days after the date of termination of employment or work assignment, whichever is earlier.

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[1] The Commission may require, as a license condition, or by rule, regulation or order pursuant to § 20.502, reports from licensees who are licensed to use radionuclides not on this list, in quantities sufficient to cause comparable radiation levels.

†Amended 41 FR 16445.

[2] A licensee whose license expires or terminates prior to, or on the last day of the calendar year, shall submit reports at the expiration or termination of the license, covering that part of the year during which the license was in effect.

[3] Individual values exactly equal to the values separating Exposure Ranges shall be reported in the higher range.

* Amended 38 FR 22220.

34 FR 5254

§ 20.409 Notifications and reports to individuals.

(a) Requirements for notifications and reports to individuals of exposure to radiation or radioactive material are specified in § 19.13 of this chapter.

(b) When a licensee is required pursuant to §§ 20.405 or 20.408 to report to the Commission any exposure of an individual to radiation or radioactive material, the licensee shall also notify the individual. Such notice shall be transmitted at a time not later than the transmittal to the Commission, and shall comply with the provisions of § 19.13(a) of this chapter.

38 FR 22220

EXCEPTIONS AND ADDITIONAL REQUIREMENTS

§ 20.501 Applications for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

§ 20.502 Additional requirements.

The Commission may, by rule, regulation, or order, impose upon any licensee such requirements, in addition to those established in the regulations in this part, as it deems appropriate or necessary to protect health or to minimize danger to life or property.

25 FR 10914

§ 20.601 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

40 FR 8774

APPENDIX A [Reserved]

APPENDIX B

Concentrations in Air and Water Above Natural Background

(See footnotes on page 20-15)

			Table I		Table II	
Element (atomic number)	Isotope [1]	†	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)
Actinium (89)	Ac 227	S	2×10^{-12}	6×10^{-5}	8×10^{-14}	2×10^{-6}
		I	3×10^{-11}	9×10^{-3}	9×10^{-13}	3×10^{-4}
	Ac 228	S	8×10^{-8}	3×10^{-3}	3×10^{-9}	9×10^{-5}
		I	2×10^{-8}	3×10^{-3}	6×10^{-10}	9×10^{-5}
Americium (95)	Am 241	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		* I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Am 242m	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	3×10^{-10}	3×10^{-3}	9×10^{-12}	9×10^{-5}
	Am 242	S	4×10^{-8}	4×10^{-3}	1×10^{-9}	1×10^{-4}
		I	5×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Am 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Am 244	S	4×10^{-6}	1×10^{-1}	1×10^{-7}	5×10^{-3}
		I	2×10^{-5}	1×10^{-1}	8×10^{-7}	5×10^{-3}
Antimony (51)	Sb 122	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
	Sb 124	S	2×10^{-7}	7×10^{-4}	5×10^{-9}	2×10^{-5}
		I	2×10^{-8}	7×10^{-4}	7×10^{-10}	2×10^{-5}
	Sb 125	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	3×10^{-8}	3×10^{-3}	9×10^{-10}	1×10^{-4}
Argon (18)	A 37	Sub[2]	6×10^{-3}		1×10^{-4}	
	A 41	Sub	2×10^{-6}		4×10^{-8}	
Arsenic (33)	As 73	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	5×10^{-4}
		I	4×10^{-7}	1×10^{-2}	1×10^{-8}	5×10^{-4}
	As 74	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	1×10^{-7}	2×10^{-3}	4×10^{-9}	5×10^{-5}
	As 76	S	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
		I	1×10^{-7}	6×10^{-4}	3×10^{-9}	2×10^{-5}
	As 77	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Astatine (85)	At 211	S	7×10^{-9}	5×10^{-5}	2×10^{-10}	2×10^{-6}
		I	3×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
Barium (56)	Ba 131	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Ba 140	S	1×10^{-7}	8×10^{-4}	4×10^{-9}	3×10^{-5}
		I	4×10^{-8}	7×10^{-4}	1×10^{-9}	2×10^{-5}
Berkelium (97)	Bk 249	S	9×10^{-10}	2×10^{-2}	3×10^{-11}	6×10^{-4}
		I	1×10^{-7}	2×10^{-2}	4×10^{-9}	6×10^{-4}
	Bk 250	S	1×10^{-7}	6×10^{-3}	5×10^{-9}	2×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Beryllium (4)	Be 7	S	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
		I	1×10^{-6}	5×10^{-2}	4×10^{-8}	2×10^{-3}
Bismuth (83)	Bi 206	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
		I	1×10^{-7}	1×10^{-3}	5×10^{-9}	4×10^{-5}
	Bi 207	S	2×10^{-7}	2×10^{-3}	6×10^{-9}	6×10^{-5}
		I	1×10^{-8}	2×10^{-3}	5×10^{-10}	6×10^{-5}
	Bi 210	S	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
		I	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
	Bi 212	S	1×10^{-7}	1×10^{-2}	3×10^{-9}	4×10^{-4}
		I	2×10^{-7}	1×10^{-2}	7×10^{-9}	4×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

			Table I		Table II	
Element (atomic number)	Isotope [1]	†	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)
Bromine (35)	Br 82	S	1×10^{-6}	8×10^{-3}	4×10^{-8}	3×10^{-4}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Cadmium (48)	Cd 109	S	5×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
		I	7×10^{-8}	5×10^{-3}	3×10^{-9}	2×10^{-4}
	Cd 115m	S	4×10^{-8}	7×10^{-4}	1×10^{-9}	3×10^{-5}
		I	4×10^{-8}	7×10^{-4}	1×10^{-9}	3×10^{-5}
	Cd 115	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Calcium (20)	Ca 45	S	3×10^{-8}	3×10^{-4}	1×10^{-9}	9×10^{-6}
		I	1×10^{-7}	5×10^{-3}	4×10^{-9}	2×10^{-4}
	Ca 47	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	3×10^{-5}
Californium (98)	Cf 249	S	2×10^{-12}	1×10^{-4}	5×10^{-14}	4×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cf 250	S	5×10^{-12}	4×10^{-4}	2×10^{-13}	1×10^{-5}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	3×10^{-5}
	Cf 251	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cf 252	* S	6×10^{-12}	2×10^{-4}	2×10^{-13}	7×10^{-6}
		* I	3×10^{-11}	2×10^{-4}	1×10^{-12}	7×10^{-6}
	Cf 253	S	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
		I	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
	Cf 254	S	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
		I	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
Carbon (6)	C 14	S	4×10^{-6}	2×10^{-2}	1×10^{-7}	8×10^{-4}
	(CO_2)	Sub	5×10^{-5}		1×10^{-6}	
Cerium (58)	Ce 141	S	4×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	2×10^{-7}	3×10^{-3}	5×10^{-9}	9×10^{-5}
	Ce 143	S	3×10^{-7}	1×10^{-3}	9×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	Ce 144	S	1×10^{-8}	3×10^{-4}	3×10^{-10}	1×10^{-5}
		I	6×10^{-9}	3×10^{-4}	2×10^{-10}	1×10^{-5}
Cesium (55)	Cs 131	S	1×10^{-5}	7×10^{-2}	4×10^{-7}	2×10^{-3}
		I	3×10^{-6}	3×10^{-2}	1×10^{-7}	9×10^{-4}
	Cs 134m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	6×10^{-3}
		I	6×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
	Cs 134	S	4×10^{-8}	3×10^{-4}	1×10^{-9}	9×10^{-6}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	4×10^{-5}
	Cs 135	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	9×10^{-8}	7×10^{-3}	3×10^{-9}	2×10^{-4}
	Cs 136	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	9×10^{-5}
		I	2×10^{-7}	2×10^{-3}	6×10^{-9}	6×10^{-5}
	Cs 137	S	6×10^{-8}	4×10^{-4}	2×10^{-9}	2×10^{-5}
		I	1×10^{-8}	1×10^{-3}	5×10^{-10}	4×10^{-5}
Chlorine (17)	Cl 36	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
		I	2×10^{-8}	2×10^{-3}	8×10^{-10}	6×10^{-5}
	Cl 38	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
Chromium (24)	Cr 51	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	2×10^{-6}	5×10^{-2}	8×10^{-8}	2×10^{-3}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Cobalt (27)	Co 57	S	3×10^{-6}	2×10^{-2}	1×10^{-7}	5×10^{-4}
		I	2×10^{-7}	1×10^{-2}	6×10^{-9}	4×10^{-4}
	Co 58m	S	2×10^{-5}	8×10^{-2}	6×10^{-7}	3×10^{-3}
		I	9×10^{-6}	6×10^{-2}	3×10^{-7}	2×10^{-3}
	Co 58	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-8}	3×10^{-3}	2×10^{-9}	9×10^{-5}
	Co 60	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	9×10^{-9}	1×10^{-3}	3×10^{-10}	3×10^{-5}
Copper (29)	Cu 64	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Curium (96)	Cm 242	S	1×10^{-10}	7×10^{-4}	4×10^{-12}	2×10^{-5}
		* I	2×10^{-10}	7×10^{-4}	6×10^{-12}	2×10^{-5}
	Cm 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	5×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cm 244	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cm 245	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 246	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 247	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	6×10^{-4}	4×10^{-12}	2×10^{-5}
	Cm 248	S	6×10^{-13}	1×10^{-5}	2×10^{-14}	4×10^{-7}
		I	1×10^{-11}	4×10^{-5}	4×10^{-13}	1×10^{-6}
	Cm 249	S	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
		I	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
Dysprosium (66)	Dy 165	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
	Dy 166	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Einsteinium (99)	Es 253	S	8×10^{-10}	7×10^{-4}	3×10^{-11}	2×10^{-5}
		I	6×10^{-10}	7×10^{-4}	2×10^{-11}	2×10^{-5}
	Es 254m	S	5×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
		I	6×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
	Es 254	S	2×10^{-11}	4×10^{-4}	6×10^{-13}	1×10^{-5}
		I	1×10^{-10}	4×10^{-4}	4×10^{-12}	1×10^{-5}
	Es 255	S	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	4×10^{-10}	8×10^{-4}	1×10^{-11}	3×10^{-5}
Erbium (68)	Er 169	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	Er 171	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Europium (63)	Eu 152 (T/2 = 9.2 hrs)	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Eu 152 (T/2 = 13 yrs)	S	1×10^{-8}	2×10^{-3}	4×10^{-10}	8×10^{-5}
		I	2×10^{-8}	2×10^{-3}	6×10^{-10}	8×10^{-5}
	Eu 154	S	4×10^{-9}	6×10^{-4}	1×10^{-10}	2×10^{-5}
		I	7×10^{-9}	6×10^{-4}	2×10^{-10}	2×10^{-5}
	Eu 155	S	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
		I	7×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Fermium (100)	Fm 254	S	6×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
		I	7×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Fm 255	S	2×10^{-8}	1×10^{-3}	6×10^{-10}	3×10^{-5}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	3×10^{-5}
	Fm 256	S	3×10^{-9}	3×10^{-5}	1×10^{-10}	9×10^{-7}
		I	2×10^{-9}	3×10^{-5}	6×10^{-11}	9×10^{-7}
Fluorine (9)	F 18	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	3×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
Gadolinium (64)	Gd 153	S	2×10^{-7}	6×10^{-3}	8×10^{-9}	2×10^{-4}
		I	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Gd 159	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Gallium (31)	Ga 72	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Germanium (32)	Ge 71	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
Gold (79)	Au 196	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
	Au 198	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Au 199	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	8×10^{-7}	4×10^{-3}	3×10^{-8}	2×10^{-4}
Hafnium (72)	Hf 181	S	4×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
		I	7×10^{-8}	2×10^{-3}	3×10^{-9}	7×10^{-5}
Holmium (67)	Ho 166	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Hydrogen (1)	H3	S	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		I	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		Sub	2×10^{-3}	....	4×10^{-5}	....
Indium (49)	In 113m	S	8×10^{-6}	4×10^{-2}	3×10^{-7}	1×10^{-3}
		I	7×10^{-6}	4×10^{-2}	2×10^{-7}	1×10^{-3}
	In 114m	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
	In 115m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	In 115	S	2×10^{-7}	3×10^{-3}	9×10^{-9}	9×10^{-5}
		I	3×10^{-8}	3×10^{-3}	1×10^{-9}	9×10^{-5}
Iodine (53)	I 125	S	5×10^{-9}	4×10^{-5}	8×10^{-11}	2×10^{-7}
		I	2×10^{-7}	6×10^{-3}	6×10^{-9}	2×10^{-4}
	I 126	S	8×10^{-9}	5×10^{-5}	9×10^{-11}	3×10^{-7}
		I	3×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	I 129	S	2×10^{-9}	1×10^{-5}	2×10^{-11}	6×10^{-8}
		I	7×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
	I 131	S	9×10^{-9}	6×10^{-5}	1×10^{-10}	3×10^{-7}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	I 132	S	2×10^{-7}	2×10^{-3}	3×10^{-9}	8×10^{-6}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	I 133	S	3×10^{-8}	2×10^{-4}	4×10^{-10}	1×10^{-6}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	I 134	S	5×10^{-7}	4×10^{-3}	6×10^{-9}	2×10^{-5}

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope ¹	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Iodine (53)	I 134	I	3×10^{-6}	2×10^{-2}	1×10^{-7}	6×10^{-4}
	I 135	S	1×10^{-7}	7×10^{-4}	1×10^{-9}	4×10^{-6}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
Iridium (77)	Ir 190	S	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Ir 192	S	1×10^{-7}	1×10^{-3}	4×10^{-9}	4×10^{-5}
		I	3×10^{-8}	1×10^{-3}	9×10^{-10}	4×10^{-5}
	Ir 194	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
Iron (26)	Fe 55	S	9×10^{-7}	2×10^{-2}	3×10^{-8}	8×10^{-4}
		I	1×10^{-6}	7×10^{-2}	3×10^{-8}	2×10^{-3}
	Fe 59	S	1×10^{-7}	2×10^{-3}	5×10^{-9}	6×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	5×10^{-5}
Krypton (36)	Kr 85m	Sub	6×10^{-6}	....	1×10^{-7}	....
	Kr 85	Sub	1×10^{-5}	....	3×10^{-7}	....
	Kr 87	Sub	1×10^{-6}	....	2×10^{-8}	....
	Kr 88	Sub	1×10^{-6}	....	2×10^{-8}	....
Lanthanum (57)	La 140	S	2×10^{-7}	7×10^{-4}	5×10^{-9}	2×10^{-5}
		I	1×10^{-7}	7×10^{-4}	4×10^{-9}	2×10^{-5}
Lead (82)	Pb 203	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	Pb 210	S	1×10^{-10}	4×10^{-6}	4×10^{-12}	1×10^{-7}
		I	2×10^{-10}	5×10^{-3}	8×10^{-12}	2×10^{-4}
	Pb 212	S	2×10^{-8}	6×10^{-4}	6×10^{-10}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
Lutetium (71)	Lu 177	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Manganese (25)	Mn 52	S	2×10^{-7}	1×10^{-3}	7×10^{-9}	3×10^{-5}
		I	1×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
	Mn 54	* S	4×10^{-7}	4×10^{-3}	1×10^{-8}	1×10^{-4}
		I	4×10^{-8}	3×10^{-3}	1×10^{-9}	1×10^{-4}
	Mn 56	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Mercury (80)	Hg 197m	S	7×10^{-7}	6×10^{-3}	3×10^{-8}	2×10^{-4}
		I	8×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Hg 197	S	1×10^{-6}	9×10^{-3}	4×10^{-8}	3×10^{-4}
		I	3×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
	Hg 203	S	7×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
Molybdenum (42)	Mo 99	S	7×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Neodymium (60)	Nd 144	S	8×10^{-11}	2×10^{-3}	3×10^{-12}	7×10^{-5}
		I	3×10^{-10}	2×10^{-3}	1×10^{-11}	8×10^{-5}
	Nd 147	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	2×10^{-3}	8×10^{-9}	6×10^{-5}
	Nd 149	S	2×10^{-6}	8×10^{-3}	6×10^{-8}	3×10^{-4}
		I	1×10^{-6}	8×10^{-3}	5×10^{-8}	3×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope ¹	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Neptunium (93)	Np 237	S	4×10^{-12}	9×10^{-5}	1×10^{-13}	3×10^{-6}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
	Np 239	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	7×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
Nickel (28)	Ni 59	S	5×10^{-7}	6×10^{-3}	2×10^{-8}	2×10^{-4}
		I	8×10^{-7}	6×10^{-2}	3×10^{-8}	2×10^{-3}
	Ni 63	S	6×10^{-8}	8×10^{-4}	2×10^{-9}	3×10^{-5}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	7×10^{-4}
	Ni 65	S	9×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Niobium (Columbium) (41).	Nb 93m	S	1×10^{-7}	1×10^{-2}	4×10^{-9}	4×10^{-4}
		I	2×10^{-7}	1×10^{-2}	5×10^{-9}	4×10^{-4}
	Nb 95	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	1×10^{-7}	3×10^{-3}	3×10^{-9}	1×10^{-4}
	Nb 97	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
Osmium (76)	Os 185	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	7×10^{-5}
	Os 191m	S	2×10^{-5}	7×10^{-2}	6×10^{-7}	3×10^{-3}
		I	9×10^{-6}	7×10^{-2}	3×10^{-7}	2×10^{-3}
	Os 191	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Os 193	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	9×10^{-9}	5×10^{-5}
Palladium (46)	Pd 103	S	1×10^{-6}	1×10^{-2}	5×10^{-8}	3×10^{-4}
		I	7×10^{-7}	8×10^{-3}	3×10^{-8}	3×10^{-4}
	Pd 109	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
Phosphorus (15)	P 32	S	7×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	8×10^{-8}	7×10^{-4}	3×10^{-9}	2×10^{-5}
Platinum (78)	Pt 191	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
	Pt 193m	S	7×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
★	Pt 193	S	1×10^{-6}	3×10^{-2}	4×10^{-8}	9×10^{-4}
		I	3×10^{-7}	5×10^{-2}	1×10^{-8}	2×10^{-3}
	Pt 197m	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
	Pt 197	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Plutonium (94)	Pu 238	S	2×10^{-12}	1×10^{-4}	7×10^{-14}	5×10^{-6}
		I	3×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 239	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 240	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 241	S	9×10^{-11}	7×10^{-3}	3×10^{-12}	2×10^{-4}
		I	4×10^{-8}	4×10^{-2}	1×10^{-9}	1×10^{-3}

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Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I		Table II	
			Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)
Plutonium (94)	Pu 242	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	9×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 243	S	2×10^{-6}	1×10^{-2}	6×10^{-8}	3×10^{-4}
		I	2×10^{-6}	1×10^{-2}	8×10^{-8}	3×10^{-4}
	Pu 244	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	4×10^{-6}
		I	3×10^{-11}	3×10^{-4}	1×10^{-12}	1×10^{-5}
Polonium (84)	Po 210	S	5×10^{-10}	2×10^{-5}	2×10^{-11}	7×10^{-7}
		I	2×10^{-10}	8×10^{-4}	7×10^{-12}	3×10^{-5}
Potassium (19)	K 42	S	2×10^{-6}	9×10^{-3}	7×10^{-8}	3×10^{-4}
		I	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
Praseodymium (59)	Pr 142	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
	Pr 143	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	5×10^{-5}
Promethium (61)	Pm 147	S	6×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
		I	1×10^{-7}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Pm 149	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
Protoactinium (91)	Pa 230	S	2×10^{-9}	7×10^{-3}	6×10^{-11}	2×10^{-4}
		I	8×10^{-10}	7×10^{-3}	3×10^{-11}	2×10^{-4}
	Pa 231	S	1×10^{-12}	3×10^{-5}	4×10^{-14}	9×10^{-7}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	2×10^{-5}
	Pa 233	S	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
		I	2×10^{-7}	3×10^{-3}	6×10^{-9}	1×10^{-4}
Radium (88)	Ra 223	S	2×10^{-9}	2×10^{-5}	6×10^{-11}	7×10^{-7}
		I	2×10^{-10}	1×10^{-4}	8×10^{-12}	4×10^{-6}
	Ra 224	S	5×10^{-9}	7×10^{-5}	2×10^{-10}	2×10^{-6}
		I	7×10^{-10}	2×10^{-4}	2×10^{-11}	5×10^{-6}
	Ra 226	S	3×10^{-11}	4×10^{-7}	3×10^{-12}	3×10^{-8}
		I	5×10^{-11}	9×10^{-4}	2×10^{-12}	3×10^{-5}
	Ra 228	S	7×10^{-11}	8×10^{-7}	2×10^{-12}	3×10^{-8}
		I	4×10^{-11}	7×10^{-4}	1×10^{-12}	3×10^{-5}
Radon (86)	Rn 220	S	3×10^{-7}	....	1×10^{-8}	....
	Rn 222[3] ***	S	*** 3×10^{-8}	....	3×10^{-9}	....
Rhenium (75)	Re 183	S	3×10^{-6}	2×10^{-2}	9×10^{-8}	6×10^{-4}
		I	2×10^{-7}	8×10^{-3}	5×10^{-9}	3×10^{-4}
	Re 186	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Re 187	S	9×10^{-6}	7×10^{-2}	3×10^{-7}	3×10^{-3}
		I	5×10^{-7}	4×10^{-2}	2×10^{-8}	2×10^{-3}
	Re 188	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Rhodium (45)	Rh 103m	S	8×10^{-5}	4×10^{-1}	3×10^{-6}	1×10^{-2}
		I	6×10^{-5}	3×10^{-1}	2×10^{-6}	1×10^{-2}
	Rh 105	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Rubidium (37)	Rb 86	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
		I	7×10^{-8}	7×10^{-4}	2×10^{-9}	2×10^{-5}
	Rb 87	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	7×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}

25 FR 10914

20-13

NOTE: Amendments made by 40 FR 60704 become effective 1/29/76.

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I		Table II	
			Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)
Ruthenium (44)	Ru 97	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	3×10^{-4}
	Ru 103	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	8×10^{-8}	2×10^{-3}	3×10^{-9}	8×10^{-5}
	Ru 105	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
	Ru 106	S	8×10^{-8}	4×10^{-4}	3×10^{-9}	1×10^{-5}
		I	6×10^{-9}	3×10^{-4}	2×10^{-10}	1×10^{-5}
Samarium (62)	Sm 147	S	7×10^{-11}	2×10^{-3}	2×10^{-12}	6×10^{-5}
		I	3×10^{-10}	2×10^{-3}	9×10^{-12}	7×10^{-5}
	Sm 151	S	6×10^{-8}	1×10^{-2}	2×10^{-9}	4×10^{-4}
		I	1×10^{-7}	1×10^{-2}	5×10^{-9}	4×10^{-4}
	Sm 153	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Scandium (21)	Sc 46	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-8}	1×10^{-3}	8×10^{-10}	4×10^{-5}
	Sc 47	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
	Sc 48	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
Selenium (34)	Se 75	S	1×10^{-6}	9×10^{-3}	4×10^{-8}	3×10^{-4}
		I	1×10^{-7}	8×10^{-3}	4×10^{-9}	3×10^{-4}
Silicon (14)	Si 31	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
		I	1×10^{-6}	6×10^{-3}	3×10^{-8}	2×10^{-4}
Silver (47)	Ag 105	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	8×10^{-8}	3×10^{-3}	3×10^{-9}	1×10^{-4}
	Ag 110m	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	1×10^{-8}	9×10^{-4}	3×10^{-10}	3×10^{-5}
	Ag 111	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
Sodium (11)	Na 22	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
		I	9×10^{-9}	9×10^{-4}	3×10^{-10}	3×10^{-5}
	Na 24	S	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
Strontium (38)	Sr 85m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	7×10^{-3}
		I	3×10^{-5}	2×10^{-1}	1×10^{-6}	7×10^{-3}
	Sr 85	S	2×10^{-7}	3×10^{-3}	8×10^{-9}	1×10^{-4}
		I	1×10^{-7}	5×10^{-3}	4×10^{-9}	2×10^{-4}
	Sr 89	S	3×10^{-8}	3×10^{-4}	3×10^{-10}	3×10^{-6}
		I	4×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
	Sr 90	S	1×10^{-9}	1×10^{-5}	3×10^{-11}	3×10^{-7}
		I	5×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
	Sr 91	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	1×10^{-3}	9×10^{-9}	5×10^{-5}
	Sr 92	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
Sulfur (16)	S 35	S	3×10^{-7}	2×10^{-3}	9×10^{-9}	6×10^{-5}
		I	3×10^{-7}	8×10^{-3}	9×10^{-9}	3×10^{-4}
Tantalum (73)	Ta 182	S	4×10^{-8}	1×10^{-3}	1×10^{-9}	4×10^{-5}
		I	2×10^{-8}	1×10^{-3}	7×10^{-10}	4×10^{-5}

25 FR 10914

NOTE: Amendments made by 40 FR 50704 become effective 1/29/76.

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Technetium (43)	Tc 96m	S	8×10^{-5}	4×10^{-1}	3×10^{-6}	1×10^{-2}
		I	3×10^{-5}	3×10^{-1}	1×10^{-6}	1×10^{-2}
	Tc 96	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Tc 97m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-7}	5×10^{-3}	5×10^{-9}	2×10^{-4}
	Tc 97	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	8×10^{-4}
	Tc 99m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	6×10^{-3}
		I	1×10^{-5}	8×10^{-2}	5×10^{-7}	3×10^{-3}
	Tc 99	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	6×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
Tellurium (52)	Te 125m	S	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
	Te 127m	S	1×10^{-7}	2×10^{-3}	5×10^{-9}	6×10^{-5}
		I	4×10^{-8}	2×10^{-3}	1×10^{-9}	5×10^{-5}
	Te 127	S	2×10^{-6}	8×10^{-3}	6×10^{-8}	3×10^{-4}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Te 129m	S	8×10^{-8}	1×10^{-3}	3×10^{-9}	3×10^{-5}
		I	3×10^{-8}	6×10^{-4}	1×10^{-9}	2×10^{-5}
	Te 129	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	4×10^{-6}	2×10^{-2}	1×10^{-7}	8×10^{-4}
	Te 131m	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
	Te 132	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
Terbium (65)	Tb 160	S	1×10^{-7}	1×10^{-3}	3×10^{-9}	4×10^{-5}
		I	3×10^{-8}	1×10^{-3}	1×10^{-9}	4×10^{-5}
Thallium (81)	Tl 200	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	1×10^{-6}	7×10^{-3}	4×10^{-8}	2×10^{-4}
	Tl 201	S	2×10^{-6}	9×10^{-3}	7×10^{-8}	3×10^{-4}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Tl 202	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	2×10^{-7}	2×10^{-3}	8×10^{-9}	7×10^{-5}
	Tl 204	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	3×10^{-8}	2×10^{-3}	9×10^{-10}	6×10^{-5}
Thorium (90)	* Th 227	S	3×10^{-10}	5×10^{-4}	1×10^{-11}	2×10^{-5}
		I	2×10^{-10}	5×10^{-4}	6×10^{-12}	2×10^{-5}
	Th 228	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	6×10^{-12}	4×10^{-4}	2×10^{-13}	1×10^{-5}
	Th 230	S	2×10^{-12}	5×10^{-5}	8×10^{-14}	2×10^{-6}
		I	1×10^{-11}	9×10^{-4}	3×10^{-13}	3×10^{-5}
	* Th 231	S	1×10^{-6}	7×10^{-3}	5×10^{-8}	2×10^{-4}
		I	1×10^{-6}	7×10^{-3}	4×10^{-8}	2×10^{-4}
	Th 232	S	3×10^{-11}	5×10^{-5}	1×10^{-12}	2×10^{-6}
		I	3×10^{-11}	1×10^{-3}	1×10^{-12}	4×10^{-5}
	** Th natural	S	6×10^{-11}	6×10^{-5}	2×10^{-12}	2×10^{-6}
		I	6×10^{-11}	6×10^{-4}	2×10^{-12}	2×10^{-5}

APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Thorium (90)	Th 234	S	6×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	3×10^{-8}	5×10^{-4}	1×10^{-9}	2×10^{-5}
Thulium (69)	Tm 170	S	4×10^{-8}	1×10^{-3}	1×10^{-9}	5×10^{-5}
		I	3×10^{-8}	1×10^{-3}	1×10^{-9}	5×10^{-5}
	Tm 171	S	1×10^{-7}	1×10^{-2}	4×10^{-9}	5×10^{-4}
		I	2×10^{-7}	1×10^{-2}	8×10^{-9}	5×10^{-4}
Tin (50)	Sn 113	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	9×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	8×10^{-5}
	Sn 125	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	8×10^{-8}	5×10^{-4}	3×10^{-9}	2×10^{-5}
Tungsten (Wolfram) (74)	W 181	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	1×10^{-7}	1×10^{-2}	4×10^{-9}	3×10^{-4}
	W 185	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
	W 187	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
Uranium (92)	U 230	S	3×10^{-10}	1×10^{-4}	1×10^{-11}	5×10^{-6}
		I	1×10^{-10}	1×10^{-4}	4×10^{-12}	5×10^{-6}
	U 232	S	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
		I	3×10^{-11}	8×10^{-4}	9×10^{-13}	3×10^{-5}
	U 233	S	5×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
	** U 234	S^4	6×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
	** U 235	S^4	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	U 236	S	6×10^{-10}	1×10^{-3}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	1×10^{-3}	4×10^{-12}	3×10^{-5}
	** U 238	S^4	7×10^{-11}	1×10^{-3}	3×10^{-12}	4×10^{-5}
		I	1×10^{-10}	1×10^{-3}	5×10^{-12}	4×10^{-5}
	U 240	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	3×10^{-5}
	** U-natural	S^4	1×10^{-10}	1×10^{-3}	5×10^{-12}	3×10^{-5}
		I	1×10^{-10}	1×10^{-3}	5×10^{-12}	3×10^{-5}
Vanadium (23)	V 48	S	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
		I	6×10^{-8}	8×10^{-4}	2×10^{-9}	3×10^{-5}
Xenon (54)	Xe 131m	Sub	2×10^{-5}	....	4×10^{-7}	....
	Xe 133	Sub	1×10^{-5}	....	3×10^{-7}	....
	Xe 133m	Sub	1×10^{-5}	....	3×10^{-7}	....
	Xe 135	Sub	4×10^{-6}	....	1×10^{-7}	....
Ytterbium (70)	Yb 175	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Yttrium (39)	Y 90	S	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
		I	1×10^{-7}	6×10^{-4}	3×10^{-9}	2×10^{-5}
	Y 91m	S	2×10^{-5}	1×10^{-1}	8×10^{-7}	3×10^{-3}
		I	2×10^{-5}	1×10^{-1}	6×10^{-7}	3×10^{-3}
	Y 91	S	4×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
		I	3×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
	Y 92	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Y 93	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}

APPENDIX B

Concentrations in Air and Water above Natural Background—Continued

(See footnotes on page 20-15)

25 FR 10914

Element (atomic number)	Isotope [1]		Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Zinc (30)	Zn 65	S	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
		I	6×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
	Zn 69m	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Zn 69	S	7×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
		I	9×10^{-6}	5×10^{-2}	3×10^{-7}	2×10^{-3}
Zirconium (40)	Zr 93	S	1×10^{-7}	2×10^{-2}	4×10^{-9}	8×10^{-4}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	8×10^{-4}
	Zr 95	S	1×10^{-7}	2×10^{-3}	4×10^{-9}	6×10^{-5}
		I	3×10^{-8}	2×10^{-3}	1×10^{-9}	6×10^{-5}
	Zr 97	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	9×10^{-8}	5×10^{-4}	3×10^{-9}	2×10^{-5}
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half-life less than 2 hours.		Sub	1×10^{-6}		3×10^{-8}	
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half-life greater than 2 hours.			3×10^{-9}	9×10^{-5}	1×10^{-10}	3×10^{-6}
Any single radionuclide not listed above, which decays by alpha emission or spontaneous fission.			6×10^{-13}	4×10^{-7}	2×10^{-14}	3×10^{-8}

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[1] Soluble (S); Insoluble (I).

[2] "Sub" means that values given are for submersion in a semispherical infinite cloud of airborne material. †

40 FR 50704

***[3] These radon concentrations are appropriate for protection from radon-222 combined with its short-lived daughters. Alternatively, the value in Table I may be replaced by one-third (⅓) "working level." (A "working level" is defined as any combination of short-lived radon-222 daughters, polonium-218, lead-214, bismuth-214 and polonium-214, in one liter of air, without regard to the degree of equilibrium, that will result in the ultimate emission of 1.3 x 10^5 MeV of alpha particle energy.) The Table II value may be replaced by one-thirtieth ($\frac{1}{30}$) of a "working level." The limit on radon-222 concentrations in restricted areas may be based on an annual average.

39 FR 23990

‡[4]. For soluble mixtures of U-238, U-234 and U-235 in air chemical toxicity may be the limiting factor. If the percent by weight (enrichment) of U-235 is less than 5, the concentration value for a 40-hour workweek, Table I, is 0.2 milligrams uranium per cubic meter of air average. For any enrichment, the product of the average concentration and time of exposure during a 40-hour workweek shall not exceed 8×10^{-4} SA μCi-hr/ml, where SA is the specific activity of the uranium inhaled. The concentration value for Table II is 0.007 milligrams uranium per cubic meter of air. The specific activity for natural uranium is 6.77×10^{-7} curies per gram U. The specific activity for other mixtures of U-238, U-235 and U-234, if not known, shall be:

$SA=3.6\times10^{-7}$ curies/gram U — U-depleted

$SA=(0.4+0.38E+0.0034E^2)\,10^{-6}$ — $E\geq0.72$

where E is the percentage by weight of U-235, expressed as percent.

*Amended 37 FR 23319.

**Amended 39 FR 23990; footnote redesignated 40 FR 50704.

***Amended 40 FR 50704.

†Amended 38 FR 29314.

‡Amended 39 FR 25463; redesignated 40 FR 50704.

NOTE: Amendments made by 40 FR 50704 become effective 1/29/76.

NOTE TO APPENDIX B

25 FR 1

NOTE: In any case where there is a mixture in air or water of more than one radionuclide, the limiting values for purposes of this Appendix should be determined as follows:

1. If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all the radionuclides in the mixture may not exceed "1" (i.e., "unity").

EXAMPLE: If radionuclides A, B, and C are present in concentrations C_A, C_B, and C_C, and if the applicable MPC's, are MPC_A, and MPC_B, and MPC_C respectively, then the concentrations shall be limited so that the following relationship exists:

$$\frac{C_A}{MPC_A}+\frac{C_B}{MPC_B}+\frac{C_C}{MPC_C}\leq 1$$

30 FR 15801

2. If either the identity or the concentration of any radionuclide in the mixture is not known, the limiting values for purposes of Appendix B shall be:

a. For purposes of Table I, Col. 1—6×10^{-13}

b. For purposes of Table I, Col. 2—4×10^{-7}

c. For purposes of Table II, Col. 1—2×10^{-14}

d. For purposes of Table II, Col. 2—3×10^{-8}

26 FR 11046

3. If any of the conditions specified below are met, the corresponding values specified below may be used in lieu of those specified in paragraph 2 above.

a. If the identity of each radionuclide in the mixture is known but the concentration of one or more of the radionuclides in the mixture is not known, the concentration limit for the mixture is the limit specified in Appendix "B" for the radionuclide in the mixture having the lowest concentration limit; or

b. If the identity of each radionuclide in the mixture is not known, but it is known that certain radionuclides specified in Appendix "B" are not present in the mixture, the concentration limit for the mixture is the lowest concentration limit specified in Appendix "B" for any radionuclide which is not known to be absent from the mixture; or

30 FR 15801

c. Element (atomic number) and isotope	Table I		Table II	
	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)	Column 1 Air (μCi/ml)	Column 2 Water (μCi/ml)
If it is known that Sr 90, I 125, I 126, I 129, I 131, (I 133, table II only), Pb 210, Po 210, At 211, Ra 223, Ra 224, Ra 226, Ac 227, Ra 228, Th 230, Pa 231, Th 232, Th-nat, Cm 248, Cf 254, and Fm 256 are not present	....	9×10^{-5}	....	3×10^{-6}
If it is known that Sr 90, I 125, I 126, I 129, (I 131, I 133, table II only), Pb 210, Po 210, Ra 223, Ra 226, Ra 228, Pa 231, Th-nat, Cm 248, Cf 254, and Fm 256 are not present	....	6×10^{-5}	....	2×10^{-6}
If it is known that Sr 90, I 129, (I 125, I 126, I 131, table II only), Pb 210, Ra 226, Ra 228, Cm 248, and Cf 254 are not present	....	2×10^{-4}	....	6×10^{-6}
If it is known that (I 129, table II only), Ra 226, and Ra 228 are not present	....	3×10^{-4}	....	1×10^{-5}
If it is known that alpha-emitters and Sr 90, I 129, Pb 210, Ac 227, Ra 228, Pa 230, Pu 241, and Bk 249 are not present	3×10^{-9}	....	1×10^{-10}	....
If it is known that alpha-emitters and Pb 210, Ac 227, Ra 228, and Pu 241 are not present	3×10^{-10}	....	1×10^{-11}	....
If it is known that alpha-emitters and Ac 227 are not present	3×10^{-11}	....	1×10^{-12}	....
If it is known that Ac 227, Th 230, Pa 231, Pu 238, Pu 239, Pu 240, Pu 242, Pu 244, Cm 248, Cf 249 and Cf 251 are not present	3×10^{-12}	....	1×10^{-13}	....

40 FR 50704

4. If a mixture of radionuclides consists of uranium and its daughters in ore dust prior to chemical separation of the uranium from the ore, the values specified below may be used for uranium and its daughters through radium-226, instead of those from paragraphs 1, 2, or 3 above.

39 FR 23990

a. For purposes of Table I, Col. 1—1×10^{-10} μCi/ml gross alpha activity; or 5×10^{-11} μCi/ml natural uranium; or 75 micrograms per cubic meter of air natural uranium.

b. For purposes of Table II, Col. 1—3×10^{-12} μCi/ml gross alpha activity; or 2×10^{-12} μCi/ml natural uranium; or 3 micrograms per cubic meter of air natural uranium.

26 FR 11046

5. For purposes of this note, a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture (C_A) to the concentration limit for that radionuclide specified in Table II of Appendix B (MPC_A) does not exceed 1/10

(i.e. $\frac{C_A}{MPC_A}\leq\frac{1}{10}$) and (b) the sum of such ratios for all the radionuclides considered as not present in the mixture does not exceed ¼

(i.e. $\frac{C_A}{MPC_A}+\frac{C_B}{MPC_B}+\ldots\ldots\leq\frac{1}{4}$).

NOTE: Amendments made by 40 FR 50704 become effective 1/29/76.

APPENDIX C

Material	Microcuries
Americium-241	.01
Antimony-122	100
Antimony-124	10
Antimony-125	10
Arsenic-73	100
Arsenic-74	10
Arsenic-76	10
Arsenic-77	100
Barium-131	10
*Barium-133	10
Barium-140	10
Bismuth-210	1
Bromine-82	10
Cadmium-109	10
Cadmium-115m	10
Cadmium-115	100
Calcium-45	10
Calcium-47	10
Carbon-14	100
Cerium-141	100
Cerium-143	100
Cerium-144	1
Cesium-131	1,000
Cesium-134m	100
Cesium-134	1
Cesium-135	10
Cesium-136	10
Cesium-137	10
Chlorine-36	10
Chlorine-38	10
Chromium-51	1,000
Cobalt-58m	10
Cobalt-58	10
Cobalt-60	1
Copper-64	100
Dysprosium-165	10
Dysprosium-166	100
Erbium-169	100
Erbium-171	100
Europium-152 9.2 h	100
Europium-152 13 yr	1
Europium-154	1
Europium-155	10
Fluorine-18	1,000
Gadolinium-153	10
Gadolinium-159	100
Gallium-72	10
Germanium-71	100
Gold-198	100
Gold-199	100
Hafnium-181	10
Holmium-166	100
Hydrogen-3	1,000
Indium-113m	100
Indium-114m	10
Indium-115m	100
Indium-115	10
Iodine-125	1
Iodine-126	1
Iodine-129	0.1
Iodine-131	1
Iodine-132	10
Iodine-133	1
Iodine-134	10
Iodine-135	10
Iridium-192	10
Iridium-194	100
Iron-55	100
Iron-59	10
Krypton-85	100
Krypton-87	10
Lanthanum-140	10
Lutetium-177	100
Manganese-52	10
Manganese-54	10
Manganese-56	10
Mercury-197m	100
Mercury-197	100
Mercury-203	10
Molybdenum-99	100
Neodymium-147	100
Neodymium-149	100
Nickel-59	100
Nickel-63	10
Nickel-65	100
Niobium-93m	10
Niobium-95	10
Niobium-97	10
Osmium-185	10
Osmium-191m*	100
Osmium-191	100
Osmium-193	100
Palladium-103	100
Palladium-109	100
Phosphorus-32	10
Platinum-191	100
Platinum-193m	100
Platinum-193	100
Platinum-197m	100
Platinum-197	100
Plutonium-239	.01
Polonium-210	0.1
Potassium-42	10
Praseodymium-142	100
Praseodymium-143	100
Promethium-147	10
Promethium-149	10
Radium-226	.01
Rhenium-186	100
Rhenium-188	100
Rhodium-103m	100
Rhodium-105	100
Rubidium-86	10
Rubidium-87	10
Ruthenium-97	100
Ruthenium-103	10
Ruthenium-105	10
Ruthenium-106	1
Samarium-151	10
Samarium-153	100
Scandium-46	10
Scandium-47	100
Scandium-48	10
Selenium-75	10
Silicon-31	100
Silver-105	10
Silver-110m	1
Silver-111	100
Sodium-24	10
Strontium-85	10
Strontium-89	1
Strontium-90	0.1
Strontium-91	10
Strontium-92	10
Sulphur-35	100
Tantalum-182	10
Technetium-96	10
Technetium-97m	100
Technetium-97	100
Technetium-99m	100
Technetium-99	10
Tellurium-125m	10
Tellurium-127m	10
Tellurium-127	100
Tellurium-129m	10
Tellurium-129	100
Tellurium-131m	10
Tellurium-132	10
Terbium-160	10
Thallium-200	100
Thallium-201	100
Thallium-202	100
Thallium-204	10
**Thorium (natural)[1]	100
Thulium-170	10
Thulium-171	10
Tin-113	10
Tin-125	10
Tungsten-181	10
Tungsten-185	10
Tungsten-187	100
**Uranium (natural)[2]	100
Uranium-233	.01
Uranium-234—Uranium-235	.01
Vanadium-48	10
Xenon-131m	1,000
Xenon-133	100
Xenon-135	100
Ytterbium-175	100
Yttrium-90	10
Yttrium-91	10
Yttrium-92	100
Yttrium-93	100
Zinc-65	10
Zinc-69m	100
Zinc-69	1,000
Zirconium-93	10
Zirconium-95	10
Zirconium-97	10
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	.01
Any radionuclide other than alpha emitting radionuclides, not listed above or mixtures of beta emitters of unknown composition	.1

NOTE: For purposes of §§ 20.303 and 20.304, where there is involved a combination of isotopes in known amounts the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity"). Example: For purposes of § 20.304, if a particular batch contains 20,000 μCi† of Au^{198} and 50,000 μCi† of C^{14}, it may also include not more than 300 μCi† of I^{131}. This limit was determined as follows:

$$\dagger\ \frac{20{,}000\ \mu Ci\ Au^{198}}{100{,}000\ \mu Ci} + \frac{50{,}000\ \mu Ci\ C^{14}}{100{,}000\ \mu Ci} + \frac{300\ \mu Ci\ I^{131}}{1{,}000\ \mu Ci} = 1$$

The denominator in each of the above ratios was obtained by multiplying the figure in the table by 1,000 as provided in § 20.304.

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[1] Based on alpha disintegration rate of Th-232, Th-230 and their daughter products.

[2] Based on alpha disintegration rate of U-238, U-234, and U-235.

* Amended 36 FR 16898.

** Amended 39 FR 23990.

† Amended 38 FR 29314.

Appendix D

UNITED STATES NUCLEAR REGULATORY COMMISSION

INSPECTION AND ENFORCEMENT REGIONAL OFFICES

Region	Address	Telephone	
		Daytime	Nights and Holidays
I Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont	Region I, USNRC Office of Inspection and Enforcement 631 Park Avenue King of Prussia, Pa. 19406	(215) 337-1150	(215) 337-1150
II* Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, Panama Canal Zone, Puerto Rico, South Carolina, Tennessee, Virginia, Virgin Islands, and West Virginia	Region II, USNRC Office of Inspection and Enforcement 230 Peachtree St., N.W. Suite 818 Atlanta, Ga. 30303	(404) 526-4503	(404) 526-4503
III Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin	Region III, USNRC Office of Inspection and Enforcement 799 Roosevelt Road Glen Ellyn, Ill. 60137	(312) 858-2660	(312) 858-2660
IV* Arkansas, Colorado, Idaho, Kansas, Louisiana, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah, and Wyoming	Region IV, USNRC Office of Inspection and Enforcement 611 Ryan Plaza Drive Suite 1000 Arlington, Texas 76012	(817)-334-2841	(817) 334-2841
V Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington, and U.S. territories and possessions in the Pacific	Region V, USNRC Office of Inspection and Enforcement 1990 N. California Blvd. Suite 202 Walnut Creek, Calif. 94596	(415) 486-3141	(415) 486-3141

40 FR 42557

NOTE: The reporting and record keeping requirements contained in §§20.205(b) and 20.205(c) and required by §20.401(b) have been approved by GAO under B-180225 (R0054). The approval expires June 30, 1977.

PART 30

RULES OF GENERAL APPLICABILITY TO LICENSING OF BYPRODUCT MATERIAL

GENERAL PROVISIONS

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RECORDS, INSPECTIONS, TESTS, PROCEDURES, AND REPORTS†

30.51 Records.
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30.53 Tests.
30.54 Control and accounting procedures for tritium.‡
30.55 Tritium reports.‡

ENFORCEMENT

30.61 Modification and revocation of licenses.
30.62 Right to cause the withholding or recall of byproduct material
30.63 Violations

SCHEDULES

30.70 Schedule A—Exempt concentrations.
30.71 Schedule B.

AUTHORITY: Secs. 81, 82, 161, 182, 183, 68 Stat. 935, 948, 953, 954, as amended (42 U.S.C. 2111, 2112, 2201, 2232, 2233); secs. 202, 206, 88 Stat. 1244, 1246 (42 U.S.C. 5842 and 5846)

Section 30.34(b) also issued under sec. 184, 68 Stat. 954, as amended (42 U.S.C. 2234). For the purposes of sec 223, 68 Stat. 958, as amended (42 U.S.C. 2273), § 30.34(c) issued under sec. 161b, 68 Stat. 948 (42 U.S.C. 2201 (b)) and §§ 30.51 and 30.52 issued under sec. 161, 68 Stat. 950, as amended (42 U.S.C 2201(o)

40 FR 8774

§ 30.1 Purpose and scope.

This part prescribes rules applicable to all persons in the United States governing licensing of byproduct material under the Atomic Energy Act of 1954, as amended (68 Stat. 919), and under Title II of the Energy Reorganization Act of 1974 (88 Stat. 1242), and exemptions from the licensing requirements permitted by section 81 of the Act.

30 FR 8185

§ 30.2 Resolution of conflict.

The requirements of this part are in addition to, and not in substitution for, other requirements of this chapter. In any conflict between the requirements in this part and a specific requirement in another part of the regulations in this chapter, the specific requirement governs.

§ 30.3 Activities requiring license.

Except for persons exempt as provided in this part and Part 150 of this chapter, no person shall manufacture, produce, transfer, receive, acquire, own possess, use, import or export byproduct material except as authorized in a specific or general license issued pursuant to the regulations in this chapter.

30 FR 8185

§ 30.4 Definitions.

As used in this part and Parts 31-36 of this chapter:

(a) "Act" means the Atomic Energy Act of 1954, (68 Stat. 919)* including any amendments thereto;

40 FR 8774

(a-1) "Administration" means the Energy Research and Development Administration or its duly authorized representatives;

30 FR 8185

(b) Terms defined in section 11 of the Act shall have the same meaning when used in the regulations in this part and Parts 31-36 to the extent such terms are not specifically defined in this part;

40 FR 8774

(c) "Agreement State" means any state with which the Atomic Energy Commission or the Nuclear Regulatory Commission has entered into an effective agreement under subsection 274b. of the Act. "Non-Agreement State" means any other State;

30 FR 8185

(d) "Byproduct material" means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material;

(e) "Commission" means the Nuclear Regulatory Commission and its duly authorized representatives;

(f) "Curie" means that amount of radioactive material which disintegrates at the rate of 37 billion atoms per second;

(g) "Government agency" means any executive department, commission, independent establishment, corporation,

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Amended 37 FR 9207.

‡ Added 37 FR 9207.

* Amended 36 FR 1466.

30 FR 8185 wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the Government;

(h) "Human use" means the internal or external administration of byproduct material, or the radiation therefrom, to human beings;

(i) "License" except where otherwise specified means a license for byproduct material issued pursuant to the regulations in this chapter;

38 FR 29314 (j)(1) "Microcurie" means that amount of radioactive material which disintegrates at the rate of 37 thousand atoms per second;

(2) "Millicurie" means that amount of radioactive material which disintegrates at the rate of 37 million atoms per second;

40 FR 8774 (k) "Person" means (1) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than the Commission or the Administration, except that the Administration shall be considered a person within the meaning of the regulations this part to the extent that its facilities and activities are subject to the licensing and related regulatory authority of the Commission pursuant to section 202 of the Energy Reorganization Act of 1974 (88 Stat. 1244),[a] any State or any political subdivision of or any political entity within a State, any foreign government or nation or any political subdivision of any such government or nation, or other entity; and (2) any legal successor, representative, agent, or agency of the foregoing;

(l) "Physician" means an individual licensed by a State or territory of the United States, the District of Columbia or the Commonwealth of Puerto Rico to dispense drugs in the practice of medicine;

30 FR 8185 (m) "Production facility" means production facility as defined in the regulations contained in Part 50 of this chapter;

(n) "Radiographer" means any individual who performs or who, in attendance at the site where the sealed source or sources are being used, personally supervises radiographic operations and who is responsible to the licensee for assuring compliance with the requirements of the Commission's regulations and the conditions of the license;

(o) "Radiographer's assistant" means any individual who, under the personal supervision of a radiographer, uses radiographic exposure devices, sealed sources or related handling tools, or radiation* survey instruments in radiography;

(p) "Radiography" means the examination of the structure of materials by nondestructive methods, utilizing sealed sources of byproduct materials;

(q) "Research and development" means (1) theoretical analysis, exploration, or experimentation; or (2) the extension of investigative findings and theories of a scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, devices, equipment, materials and processes. "Research and development" as used in this part and Parts 31-36 does not include the internal or external administration of byproduct material, or the radiation therefrom, to human beings;

(r) "Sealed source" means any byproduct material that is encased in a capsule designed to prevent leakage or escape of the byproduct material;

(s) "Source material" means source material as defined in the regulations contained in Part 40 of this chapter;

(t) "Special nuclear material" means special nuclear material as defined in the regulations contained in Part 70 of this chapter;

(u) "United States", when used in a geographical sense, includes all territories and possessions of the United States, the Canal Zone and Puerto Rico;

(v) "Utilization facility" means a utilization facility as defined in the regulations contained in Part 50 of this chapter.

37 FR 5745 (w) "Commencement of construction" means any clearing of land, excavation, or other substantial action that would adversely affect the natural environment of a site but does not include changes desirable for the temporary use of the land for public recreational uses, necessary borings to determine site characteristics or other preconstruction monitoring to establish background information related to the suitability of a site or to the protection of environmental values.

30 FR 8185

§ 30.5 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part and Parts 31-36 by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

§ 30.6 Communications.

Except where otherwise specified, all communications and reports concerning the regulations in this part and Parts 31-36 and applications filed under them, should be addressed to the Director of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C., 20555. Communications, reports and applications may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C., or **7920 Norfolk Avenue, Bethesda, Md.

EXEMPTIONS

§ 30.11 Specific exemptions.[1]

37 FR 5745 (a) The Commission may, upon application of any interested person or upon its own initiative, grant such exemptions from the requirements of the regulations in this part and Parts 31-36 of this chapter as it determines are authorized by law and will not endanger life or property or the common defense and security and are otherwise in the public interest.

(b) Any person subject to the provisions of §§ 30.32(f) and 30.33(a)(5) may request an exemption from the requirements of those provisions. The Commission may grant an exemption from the provisions of § 30.32(f) and 30.33(a)(5) upon considering and balancing the following factors:

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[a] The Administration facilities and activities identified in section 202 are:

(1) Demonstration Liquid Metal Fast Breeder reactors when operated as part of the power generation facilities of an electric utility system, or when operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor.

(2) Other demonstration nuclear reactors, except those in existence on January 19, 1975, when operated as part of the power generation facilities of an electric utility system, or when operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor.

(3) Facilities used primarily for the receipt and storage of high-level radioactive wastes resulting from licensed activities.

(4) Retrievable Surface Storage Facilities other facilities authorized for the express purpose of subsequent long-term storage of high-level radioactive waste generated by the Administration, which are not used for, or are part of, research and development activities.

* Amended 36 FR 1466.

[1] Issuance of an exemption by the Nuclear Regulatory Commission for export of byproduct material contained in materials or products does not relieve any person from complying with the licensing requirements and regulations of the Department of Commerce applicable to the export of the materials or the products containing such byproduct materials.

** Amended 34 FR 19546.

(1) Whether conduct of the proposed activities will give rise to a significant adverse impact on the environment and the nature and extent of such impact, if any;

(2) Whether redress of any adverse environmental impact from conduct of the proposed activities can reasonably be effected should such redress by necessary;

(3) Whether conduct of the proposed activities would foreclose subsequent adoption of alternatives; and

(4) The effect of delay in conducting such activities on public interest. During the period of any exemption granted pursuant to this paragraph (b), any activities conducted shall be carrird out in such a manner as will minimize or reduce their environmental impact.

§ 30.12 Persons using byproduct material under certain Energy Research and Development Administration and Nuclear Regulatory Commission contracts.

Except to the extent that Administration facilities or activities of the types subject to licensing pursuant to section 2 of the Energy Reorganization Act of 74 are involved, any prime contractor of the Administration is exempt from the requirements for a license set forth in sections 8 and 82 of the Act and from the regulations in this part to the extent that such contractor, under his prime contract with the Administration manufactures, produces, transfers, receives, acquires, owns, possesses, uses, imports, or exports byproduct material for: (a) the performance of work for the Administration at a United States Government-owned or controlled site, including the transportation of by product material to or from such site and the performance of contract services during temporary interruptions of such transportation; (b) research in, or development, manufacture, storage, testing or transportation of, atomic weapons or components thereof; or (c) the use or operation of nuclear reactors or other nuclear devices in a United States Government-owned vehicle or vessel. In addition to the foregoing exemptions and subject to the requirement for licensing of Administration facilities and activities pursuant to section 202 of the Energy Reorganization Act of 1974, any prime contractor or subcontractor of the Administration or the Commission is exempt from the requirements for a license set forth in sections 81 and 82 of the Act and from the regulations in this part to the extent that such prime contractor or subcontractor manufactures, produces, transfers, receives, acquires, owns, possesses, uses, imports or exports byproduct material under his prime contract or subcontract when the Commission determines that the exemption of the prime contractor or subcontractor is authorized by law; and that, under the terms of the contract or subcontract, there is adequate assurance that the work thereunder can be accomplished without undue risk to the public health and safety.

40 FR 8774

§ 30.13 Carriers.

Common and contract carriers, freight forwarders, warehousemen, and the U.S. Postal Service are exempt from the regulations in this part and Parts 31-36 of this chapter and the requirements for a license set forth in section 81 of the Act to the extent that they transport or store byproduct material in the regular course of carriage for another or storage incident thereto.

37 FR 3985

§ 30.14 Exempt concentrations.

(a) Except as provided in paragraphs (c) ~~and (d) of this section~~, any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in this part and Parts 31-36 of this chapter to the extent that such person receives, possesses, uses, transfers, owns or acquires products or materials containing byproduct material in concentrations not in excess of those listed in § 30.70.

(b) This section shall not be deemed to authorize the import of byproduct material or products containing byproduct material.

(c) A manufacturer, processor, or producer of a product or material in an Agreement State is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in this part and Parts 31, 32, 33, 34 and 36, to the extent that he transfers byproduct material contained in a product or material in concentrations not in excess of those specified in § 30.70 and introduced into the product or material by a licensee holding a specific license issued by an Agreement State, the Commission, or the Atomic Energy Commission expressly authorizing such introduction. This exemption does not apply to the transfer of byproduct material contained in any food, beverage, cosmetic, drug, or other commodity or product designed for ingestion or inhalation by or application to, a human being.

(d) No person may introduce byproduct material into a product or material knowing or having reason to believe that it will be transferred to persons exempt under this section or equivalent regulations of an Agreement State, except in accordance with a license issued prusuant to § 32.11 of this chapter or the general license provided in § 150.20 of Part 150.

30 FR 8185

§ 30.15 Certain items containing byproduct material.

34 FR 19546

(a) Except for persons who apply byproduct material to, or persons who incorporate byproduct material into, the following products, or persons who import for sale or distribution the following products containing byproduct material, any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 20 and 30-36 of this chapter to the extent that such person receives, possesses, uses, transfers, exports, owns, or acquires the following products:

34 FR 6651

(1) Timepieces or hands or dials containing not more than the following specified quantities of byproduct material and not exceeding the following specified levels of radiation:

(i) 25 millicuries of tritium per timepiece.

(ii) 5 millicuries of tritium per hand.

(iii) 15 millicuries of tritium per dial (bezels when used shall be considered as part of the dial).

(iv) 100 microcuries of promethium-147 per watch or 200 microcuries of promethium-147 per any other timepiece.

(v) 20 microcuries of promethium-147 per watch hand or 40 microcuries of promethium-147 per other timepiece hand.

(vi) 60 microcuries of promethium-147 per watch dial or 120 microcuries of promethium-147 per other timepiece dial (bezels when used shall be considered as part of the dial).

(vii) The levels of radiation from hands and dials containing promethium-147 will not exceed, when measured through 50 milligrams per square centimeter of absorber:

(a) For wrist watches, 0.1 millirad per hour at 10 centimeters from any surface.

(b) For pocket watches, 0.1 millirad per hour at 1 centimeter from any surface.

(c) For any other timepiece, 0.2

32 FR 13920

millirad per hour at 10 centimeters from any surface.

(2) Lock illuminators containing not more than 15 millicuries of tritium or not more than 2 millicuries of promethium-147 installed in automobile locks. The levels of radiation from each lock illuminator containing promethium-147 will not exceed 1 millirad per hour at 1 centimeter from any surface when measured through 50 milligrams per square centimeter of absorber.

(3) Balances of precision containing not more than 1 millicurie of tritium per balance or not more than 0.5 millicurie of tritium per balance part.

(4) Automobile shift quadrants containing not more than 25 millicuries of tritium.

(5) Marine compasses containing not more than 750 millicuries of tritium gas and other marine navigational instruments containing not more than 250 millicuries of tritium gas.

(6) Thermostat dials and pointers containing not more than 25 millicuries of tritium per thermostat.

(7) **

(8) Electron tubes: *Provided*, That each tube does not contain more than one of the following specified quantities of byproduct material:

(i) 150 millicuries of tritium per microwave receiver protector tube or 10 millicuries of tritium per any other electron tube;

(ii) 1 microcurie of cobalt-60;

(iii) 5 microcuries of nickel-63;

(iv) 30 microcuries of krypton-85;

(v) 5 microcuries of cesium-137;

(vi) 30 microcuries of promethium-147;

And provided further, That the levels of radiation from each electron tube containing byproduct material do not exceed 1 millirad per hour at 1 centimeter from any surface when measured through 7 milligrams per square centimeter of absorber.[3]

(9) **Ionizing radiation measuring instruments containing, for purposes of internal calibration or standardization, a** source of byproduct material not exceeding the applicable quantity set forth in § 30.71, Schedule B.

(b) Any person who desires to apply byproduct material to, or to incorporate byproduct material into, the products exempted in paragraph (a) of this section, or who desires to import for sale or distribution such products containing byproduct material, should apply for a specific license pursuant to § 32.14 of this chapter, which license states that the product may be distributed by the licensee to persons exempt from the regulations pursuant to paragraph (a) of this section.

§ 30.16 Resins containing scandium-46 and designed for sand-consolidation in oil wells.

Any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 20 and 30-36 of this chapter to the extent that such person receives, possesses, uses, transfers, exports, owns, or acquires synthetic plastic resins containing scandium-46 which are designed for sand-consolidation in oil wells, and which have been manufactured or imported for sale or distribution, in accordance with a specific license issued pursuant to § 32.17 of this chapter or equivalent regulations of an Agreement State. The exemption in this section does not authorize the manufacture or import of any resins containing scandium-46.

§ 30.18 Exempt quantities.

(a) Except as provided in paragraphs (c) and (d) of this section, any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 30-34 of this chapter to the extent that such person receives, possesses, uses, transfers, owns, or acquires byproduct material in individual quantities each of which does not exceed the applicable quantity set forth in § 30.71, Schedule B.

(b) Any person who possesses byproduct material received or acquired prior to September 25, 1971, under the general license then provided in § 31.4 of this chapter is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 30-34 of this chapter to the extent that such person possesses, uses, transfers, or owns such byproduct material.

(c) This section does not authorize the production, packaging, repackaging, or import of byproduct material for purposes of commercial distribution, or the incorporation of byproduct material into products intended for commercial distribution.

(d) No person may, for purposes of commercial distribution, import or transfer byproduct material in the individual quantities set forth in § 30.71 Schedule B, knowing or having reason to believe that such quantities of byproduct material will be transferred to persons exempt under this section or equivalent regulations of an Agreement State, except in accordance with a license issued under § 32.18 of this chapter, which license states that the byproduct material may be transferred by the licensee to persons exempt under this section or the equivalent regulations of an Agreement State.

§ 30.19 Self-luminous products containing tritium, krypton-85, or promethium-147.

(a) Except for persons who manufacture, process, or produce self-luminous products containing tritium, krypton-85, or promethium-147, or who import such products, and except as provided in paragraph (c) of this section, any person is exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 20 and 30-36 of this chapter to the extent that such person receives, possesses, uses, transfers, exports, owns, or acquires tritium, krypton-85, or promethium-147 in self-luminous products manufactured, processed, produced, imported, or transferred in accordance with a specific license issued pursuant to § 32.22 of this chapter, which license authorizes the transfer of the product for use under this section.

(b) Any person who desires to manufacture, process, or produce self-luminous products containing tritium, krypton-85, or promethium-147, or to transfer or to import such products for use pursuant to paragraph (a) of this section, should apply for a license pursuant to § 32.22 of this chapter, which license states that the product may be transferred by the licensee to persons exempt from the regulations pursuant to paragraph (a) of this section or equivalent regulations of an Agreement State.

(c) The exemption in paragraph (a) of this section does not apply to tritium, krypton-85, or promethium-147 used in products primarily for frivolous purposes or in toys or adornments.

§ 30.20 Gas and aerosol detectors containing byproduct material.

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[3] For purposes of this subparagraph "electron tubes" include spark gap tubes, power tubes, gas tubes including glow lamps, receiving tubes, microwave tubes, indicator tubes, pickup tubes, radiation detection tubes, and any other completely sealed tube that is designed to conduct or control electrical currents.

**Deleted 34 FR 6651.

34 FR 6653

(a) Except for persons who manufacture, process, or produce gas and aerosol detectors containing byproduct material who import such products, any person exempt from the requirements for a license set forth in section 81 of the Act and from the regulations in Parts 20 and 30-36 of this chapter to the extent that such person receives, possesses, uses, transfers, exports, owns, or acquires byproduct material in gas and aerosol detectors designed to protect life or property from fires and airborne hazards, and manufactured, processed, produced, imported, or transferred in accordance with a specific license issued pursuant to § 32.26 of this chapter, which license authorizes the transfer of the product for use under this section.

(b) Any person who desires to manufacture, process, or produce gas and aerosol detectors containing byproduct material, or to import or to transfer such products for use pursuant to paragraph (a) of this section, should apply for a license pursuant to § 32.26 of this chapter, which license states that the product may be transferred by the licensee to persons exempt from the regulations pursuant to paragraph (a) of this section or equivalent regulations of an Agreement State.

LICENSES

30.31 Types of licenses.

30 FR 8185

Licenses for byproduct material are of two types: General and specific. Specific licenses are issued to named persons upon applications filed pursuant to the regulations in this part and Parts 32-36. General licenses are effective without the filing of applications with the Commission or the issuance of licensing documents to particular persons.

§ 30.32 Application for specific licenses.

40 FR 50703

(a) Applications for specific licenses should be filed in duplicate on Form NRC-313, "Application for Byproduct Material License," with the Director of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

40 FR 8774

Applications may be filed in person at the Commission's offices at 1717 H Street, N.W., Washington, D.C., or 7920 Norfolk Avenue, Bethesda, Maryland. Information contained in previous applications, statements, or reports filed with the Commission or the Atomic Energy Commission may be incorporated by reference, provided that such references are clear and specific.

30 FR 8185

(b) The Commission may at any time after the filing of the original application, and before the expiration of the license, require further statements in order to enable the Commission to determine whether the application should be granted or denied or whether a license, should be modified or revoked.

(c) Each application shall be signed by the applicant or licensee or a person duly authorized to act for and on his behalf.

(d) An application for license filed pursuant to the regulations in this part and Parts 32-36 will be considered also as an application for licenses authorizing other activities for which licenses are required by the Act, provided that the application specifies the additional activities for which licenses are requested and complies with regulations of the Commission as to applications for such licenses.

38 FR 145

(e) Each application for a byproduct material license, other than a license exempted from Part 170 of this chapter, shall be accompanied by the fee prescribed in § 170.31 of this chapter. No fee will be required to accompany an application for renewal or amendment of a license, except as provided in § 170.31 of this chapter.

37 FR 5745

(f) An application for a license to receive and possess byproduct material for commercial waste disposal by land burial or for the conduct of any other activity which the Commission determines will significantly affect the quality of the environment shall be filed at least 9 months prior to commencement of construction of the plant or facility in which the activity will be conducted and shall be accompanied by any Environmental Report required pursuant to Part 51** of this chapter.

§ 30.33 General requirements for issuance of specific licenses.

30 FR 8185

(a) An application for a specific license will be approved if:

(1) The application is for a purpose authorized by the Act;

(2) The applicant's proposed equipment and facilities are adequate to protect health and minimize danger to life or property.

(3) The applicant is qualified by training and experience to use the material for the purpose requested in such manner as to protect health and minimize danger to life or property;

(4) The applicant satisfies any special requirements contained in Parts 32-36; and

37 FR 5745

(5) In the case of an application for a license to receive and possess byproduct material for commercial waste disposal by land burial or for the conduct of any other activity which the Commission determines will significantly affect the quality of the environment, the Director of Nuclear Material Safety and Safeguards or his designee, before commencement of construction of the plant or facility in which the activity will be conducted, on the basis of information filed and evaluations made pursuant to Part 51** of this chapter, has concluded, after weighing the environmental, economic, technical, and other benefits against environmental costs and considering available alternatives, that the action called for is the issuance of the proposed license, with any appropriate conditions to protect environmental values. Commencement of construction prior to such conclusion may be grounds for denial of a license to receive and possess byproduct material in such plant or facility.

30 FR 8185

(b) Upon a determination that an application meets the requirements of the Act, and the regulations of the Commission, the Commission will issue a specific license authorizing the possession and use of byproduct material (Form NRC-374, "Byproduct Material License").

§ 30.34 Terms and conditions of licenses.

(a) Each license issued pursuant to the regulations in this part and the regulations in Parts 31-36 shall be subject to all the provisions of the Act, now or hereafter in effect, and to all valid rules, regulations and orders of the Commission.

(b) No license issued or granted pursuant to the regulations in this part and Parts 31-36, nor any right under a license shall be transferred, assigned or in any manner disposed of, either voluntarily or involuntarily, directly or indirectly, through transfer of control of any license to any person, unless the Commission shall, after securing full information, find that the transfer is in accordance with the provisions of the Act and shall give its consent in writing.

38 FR 33968

(c) Each person licensed by the Commission pursuant to the regulations in this part and Parts 31-36 shall confine his possession and use of the byproduct material to the locations and purposes authorized in the license. Except as otherwise provided in the license, a

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**Amended 39 FR 26279.

38 FR 33968

license issued pursuant to the regulations in this part and Parts 31-36 of this chapter shall carry with it the right to receive, acquire, own, possess, and import byproduct material. Preparation for shipment and transport of byproduct material shall be in accordance with the provisions of Part 71 of this chapter.

30 FR 8185

(d) Each license issued pursuant to the regulations in this part and Parts 31-36 shall be deemed to contain the provisions set forth in section 183b.-d., inclusive, of the Act, whether or not these provisions are expressly set forth in the license.

(e) The Commission may incorporate, in any license issued pursuant to the regulations in this part and Parts 31-36, at the time of issuance, or thereafter by appropriate rule, regulation or order, such additional requirements and conditions with respect to the licensee's receipt, possession, use and transfer of byproduct material as it deems appropriate or necessary in order to:

(1) Promote the common defense and security;

(2) Protect health or to minimize danger to life or property;

(3) Protect restricted data;

(4) Require such reports and the keeping of such records, and to provide for such inspections of activities under the license as may be necessary or appropriate to effectuate the purposes of the Act and regulations thereunder.

§ 30.35 [Deleted 40 FR 8774.]

30 FR 8185

§ 30.36 Expiration of licenses.

Except as provided in § 30.37(b), each specific license shall expire at the end of the day, in the month and year stated therein.

§ 30.37 Applications for renewal of licenses.

(a) Applications for renewal of a specific license shall be filed in accordance with § 30.32.

(b) In any case in which a licensee, not less than thirty (30) days prior to the expiration of his existing license, has filed an application in proper form for renewal or for a new license, such existing license shall not expire until the application has been finally determined by the Commission.

§ 30.38 Applications for amendment of licenses.

Applications for amendment of a license shall be filed in accordance with § 30.32 and shall specify the respects in which the licensee desires his license to be amended and the grounds for such amendment.

30 FR 8185

§ 30.39 Commission action on applications to renew or amend.

In considering an application by a licensee to renew or amend his license the Commission will apply the applicable criteria set forth in § 30.33 and Parts 32-36 of this chapter.

38 FR 33968

§ 30.41 Transfer of byproduct material.

(a) No licensee shall transfer byproduct material except as authorized pursuant to this section.

(b) Except as otherwise provided in his license and subject to the provisions of paragraphs (c) and (d) of this section, any licensee may transfer byproduct material:

(1) To the Administration;

40 FR 8774

(2) To the agency in any Agreement State which regulates radioactive material pursuant to an agreement under section 274 of the Act;

38 FR 33968

(3) To any person exempt from the licensing requirements of the Act and regulations in this part, to the extent permitted under such exemption;

(4) To any person in an Agreement State, subject to the jurisdiction of that State, who has been exempted from the licensing requirements and regulations of that State, to the extent permitted under such exemption;

(5) To any person authorized to receive such byproduct material under terms of a specific license or a general license or their equivalents issued by the Atomic Energy Commission, the Commission, or an Agreement State; or

(6) As otherwise authorized by the Commission in writing.

(c) Before transferring byproduct material to a specific licensee of the Commission or an Agreement State or to a general licensee who is required to register with the Commission or with an Agreement State prior to receipt of the byproduct material, the licensee transferring the material shall verify that the transferee's license authorizes the receipt of the type, form, and quantity of byproduct material to be transferred.

(d) The following methods for the verification required by paragraph (c) of this section are acceptable:

(1) The transferor may have in his possession, and read, a current copy of the transferee's specific license or registration certificate;

38 FR 33968

(2) The transferor may have in his possession a written certification by the transferee that he is authorized by license or registration certificate to receive the type, form, and quantity of byproduct material to be transferred, specifying the license or registration certificate number, issuing agency and expiration date;

(3) For emergency shipments the transferor may accept oral certification by the transferee that he is authorized by license or registration certificate to receive the type, form, and quantity of byproduct material to be transferred, specifying the license or registration certificate number, issuing agency and expiration date: *Provided*, That the oral certification is confirmed in writing within 10 days;

(4) The transferor may obtain other sources of information compiled by a reporting service from official records of the Commission or the licensing agency of an Agreement State as to the identity of licensees and the scope and expiration dates of licenses and registration; or

(5) When none of the methods of verification described in paragraphs (d)(1) to (4) of this section are readily available or when a transferor desires to verify that information received by one of such methods is correct or up-to-date, the transferor may obtain and record confirmation from the Commission or the licensing agency of an Agreement State that the transferee is licensed to receive the byproduct material.

30 FR 8185

RECORDS, INSPECTIONS, TESTS, PROCEDURES, AND REPORTS†

§ 30.51 Records.

Each person who receives byproduct material pursuant to a license issued pursuant to the regulations in this part and Parts 31-36 shall keep records showing the receipt, transfer, export and disposal of such byproduct material.

§ 30.52 Inspections.

(a) Each licensee shall afford to the Commission at all reasonable times opportunity to inspect byproduct material and the premises and facilities wherein byproduct material is used or stored.

(b) Each licensee shall make available to the Commission for inspection, upon reasonable notice, records kept by him pursuant to the regulations in this chapter.

§ 30.53 Tests.

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† Amended 37 FR 9207.

30 FR 8185

Each licensee shall perform, or permit the Commission to perform, such tests as the Commission deems appropriate or necessary for the administration of the regulations in this part and Parts 31-36, including tests of:

(a) Byproduct material;

(b) Facilities wherein byproduct material is utilized or stored;

(c) Radiation detection and monitoring instruments; and

(d) Other equipment and devices used in connection with the utilization or storage of byproduct material.

37 FR 9207

§ 30.54 Control and accounting procedures for tritium.

(a) Except as specified in paragraph (b) of this section, each licensee who is authorized to possess at any one time and location more than 10,000 curies of tritium shall establish and maintain written material control and accounting procedures that are sufficient to enable the licensee to account for the tritium in his possession under specific license.

(b) Written material control and accounting procedures are not required for (1) tritium produced or possessed within a production or utilization facility incidental to the operation of the facility; (2) tritium contained in spent fuel, other than tritium intentionally produced in or recovered from a production or utilization facility for any subsequent use; (3) tritium contained in devices imported by persons licensed to transfer such devices to persons exempt from licensing pursuant to § 30.15; and (4) tritium contained in self-luminous devices imported by persons licensed to transfer such devices to persons exempt from licensing pursuant to § 30.19.

§ 30.55 Tritium reports.

(a) Except as specified in paragraph (d) of this section, each licensee who transfers or receives at any one time 1,000 curies or more of tritium shall complete and distribute a Nuclear Material Transaction* Report on Form NRC-741, in accordance with the printed instructions for completing the form. Each licensee who transfers such material shall submit a completed copy of Form NRC-741 to the Commission and three copies to the receiver of the material promptly after the transfer takes place. Each licensee who receives such material shall submit a completed copy of Form NRC-741 to the Commission and to the shipper of the material within ten (10) days after the material is received. The Commission's copies of the report shall be submitted to the U.S. Energy Research and Development Administration, Post Office Box E, Oak Ridge, Tennessee 37830, and shall include the Reporting Identification Symbol (RIS) assigned by the Commission to the licensee.

40 FR 8774

(b) Except as specified in paragraph (d) and (e) of this section, each licensee who is authorized to possess at any one time and location more than 10,000 curies of tritium shall submit to the Commission within thirty (30) days after June 30 and December 31 of each year a statement of his tritium inventory to the nearest hundredth of a gram calculated at 10,000 curies per gram.

37 FR 9207

The reports shall be submitted to the U.S. Energy Research and Development Administration, Post Office Box E, Oak Ridge, Tennessee 37830, and shall include the Reporting Identification Symbol (RIS) assigned by the Commission to the licensee.

41 FR 16445

(c) Except as specified in paragraph (d) of this section, each licensee who is authorized to possess, import, or export tritium shall report promptly to the appropriate NRC Regional Office listed in Appendix D of Part 20 of this chapter by telephone and telegraph, mailgram, or facsimile any incident in which an attempt has been made or is believed to have been made to commit a theft or unlawful diversion of more than 10 curies of such material at any one time or more than 100 curies of such material in any one calendar year. The initial report shall be followed within a period of fifteen (15) days by a written report submitted to the appropriate NRC Regional Office which sets forth the details of the incident and its consequences. Copies of such written report shall be sent to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

37 FR 9207

Subsequent to the submission of the written report required by this paragraph, the licensee shall promptly inform the Office of Inspection and Enforcement by means of a written report of any substantive additional information, which becomes available to the licensee, concerning an attempted or apparent theft or unlawful diversion of tritium.

(d) The reports described in this section are not required for tritium possessed pursuant to a general license provided in Part 31 of this chapter or for tritium contained in spent fuel.

(e) The reports described in paragraph (b) of this section are not required for (1) tritium produced or possessed within a production or utilization facility incidental to the operation of the facility, other than tritium intentionally produced by or recovered from a production or utilization facility for any subsequent use; (2) tritium contained in devices imported by persons licensed to transfer such devices to persons exempt from licensing pursuant to § 30.15, or (3) tritium contained in self-luminous devices imported by persons licensed to transfer such devices to persons exempt from licensing pursuant to § 30.19.

30 FR 8185

ENFORCEMENT

§ 30.61 Modification and revocation of licenses.

(a) The terms and conditions of each license issued pursuant to the regualtions in this part and Parts 31-36 shall be subject to amendment, revision or modification by reason of amendments to the Act, or by reason of rules, regulations and orders issued in accordance with the terms of the Act.

(b) Any license may be revoked, suspended or modified, in whole or in part, for any material false statement in the application or any statement of fact required under section 182 of the Act, or because of conditions revealed by such application or statement of fact or any report, record or inspection or other means which would warrant the Commission to refuse to grant a license on an original application, or for violation of, or failure to observe any of the terms and provisions of the Act or of any rule, regulation or order of the Commission.

(c) Except in cases of willfulness or those in which the public health, interest or safety requires otherwise, no license shall be modified, suspended or revoked unless, prior to the institution of proceedings therefor, facts or conduct which may warrent such action shall have been called to the attention of the licensee in writing and the licensee shall have been accorded an opportunity to demonstrate or achieve compliance with all lawful requirements.

40 FR 8774

§ 30.62 Right to cause the withholding or recall of byproduct materials.

30 FR 8185

The Commission may cause the withholding or recall of byproduct material from any licensee who is not equipped to observe or fails to observe such safety standards to protect health as may be estabiished by the Commission, or who uses such materials in violation of law or regulation of the Commission, or in a manner other than as disclosed in the application therefor or approved by the Commission.

40 FR 8774

§ 30.63 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

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* Amended 38 FR 2330.

40 FR 3774

SCHEDULES

§ 30.70 Schedule A—Exempt concentrations.

30 FR 8185

Element (atomic number)	Isotope	Column I Gas concentration $\mu Ci/ml^{1}$ †	Column II Liquid and solid concentration $\mu Ci/ml^{2}$ †
Antimony (51)	Sb 122		3×10^{-4}
	Sb 124		2×10^{-4}
	Sb 125		1×10^{-3}
Argon (18)	A 37	1×10^{-3}	
	A 41	4×10^{-7}	
Arsenic (33)	As 73		5×10^{-3}
	As 74		5×10^{-4}
	As 76		2×10^{-4}
	As 77		8×10^{-4}
Barium (56)	Ba 131		2×10^{-3}
	Ba 140		3×10^{-4}
Beryllium (4)	Be 7		2×10^{-2}
Bismuth (83)	Bi 206		4×10^{-4}
Bromine (35)	Br 82	4×10^{-7}	3×10^{-3}
Cadmium (48)	Cd 109		2×10^{-3}
	Cd 115m		3×10^{-4}
	Cd 115		3×10^{-4}
Calcium (20)	Ca 45		9×10^{-5}
	Ca 47		5×10^{-4}
Carbon (6)	C 14	1×10^{-6}	8×10^{-3}
Cerium (58)	Ce 141		9×10^{-4}
	Ce 143		4×10^{-4}
	Ce 144		1×10^{-4}
Cesium (55)	Cs 131		2×10^{-2}
	Cs 134m		6×10^{-2}
	Cs 134		9×10^{-5}
Chlorine (17)	Cl 38	9×10^{-7}	4×10^{-3}
Chromium (24)	Cr 51		2×10^{-2}
Cobalt (27)	Co 57		5×10^{-3}
	Co 58		1×10^{-3}
	Co 60		5×10^{-4}
Copper (29)	Cu 64		3×10^{-3}
Dysprosium (66)	Dy 165		4×10^{-3}
	Dy 166		4×10^{-4}
Erbium (68)	Er 169		9×10^{-4}
	Er 171		1×10^{-3}
Europium (63)	Eu 152 (T/2=9.2 Hrs)		6×10^{-4}
	Eu 155		2×10^{-3}
Fluorine (9)	F 18	2×10^{-6}	8×10^{-3}
Gadolinium (64)	Gd 153		2×10^{-3}
	Gd 159		8×10^{-4}
Gallium (31)	Ga 72		4×10^{-4}
Germanium (32)	Ge 71		2×10^{-2}
Gold (79)	Au 196		2×10^{-3}
	Au 198		5×10^{-4}
	Au 199		2×10^{-3}
Hafnium (72)	Hf 181		7×10^{-4}
Hydrogen (1)	H 3	5×10^{-6}	3×10^{-2}
Indium (49)	In 113m		1×10^{-2}
	In 114m		2×10^{-4}
Iodine (53)	I 126	3×10^{-9}	2×[illegible]
	I 131	3×10^{-9}	2[illegible]
	I 132	8×10^{-8}	6×[illegible]
	I 133	1×10^{-8}	7×10^{-5}
	I 134	2×10^{-7}	1×10^{-3}
Iridium (77)	Ir 190		2×10^{-3}
	Ir 192		4×10^{-4}
	Ir 194		3×10^{-4}
Iron (26)	Fe 55		8×10^{-3}
	Fe 59		6×10^{-4}
Krypton (36)	Kr 85m	1×10^{-6}	
	Kr 85	3×10^{-6}	
Lanthanum (57)	La 140		2×10^{-4}
Lead (82)	Pb 203		4×10^{-3}
Lutetium (71)	Lu 177		1×10^{-3}
Manganese (25)	Mn 52		3×10^{-4}
	Mn 54		1×10^{-3}
	Mn 56		1×10^{-3}
Mercury (80)	Hg 197m		2×10^{-3}
	Hg 197		3×10^{-3}
	Hg 203		2×10^{-4}
Molybdenum (42)	Mo 99		2×10^{-3}
Neodymium (60)	Nd 147		6×10^{-4}
	Nd 149		3×10^{-3}
Nickel (28)	Ni 65		1×10^{-3}
Niobium (Columbium) (41).	Nb 95		1×10^{-3}
	Nb 97		9×10^{-3}
Osmium (76)	Os 185		7×10^{-4}
	Os 191m		3×10^{-2}
	Os 191		2×10^{-3}
	Os 193		6×10^{-4}
Palladium (46)	Pd 103		3×10^{-3}
	Pd 109		9×10^{-4}
Phosphorus (15)	P 32		2×10^{-4}
Platinum (78)	Pt 191		1×10^{-3}
	Pt 193m		1×10^{-2}
	Pt 197m		1×10^{-2}
	Pt 197		1×10^{-3}
Potassium (19)	K 42		3×10^{-3}
Praseodymium (59).	Pr 142		3×10^{-4}
	Pr 143		5×10^{-4}
Promethium (61)	Pm 147		2×10^{-3}
	Pm 149		4×10^{-4}
Rhenium (75)	Re 183		6×10^{-3}
	Re 186		9×10^{-4}
	Re 188		6×10^{-4}
Rhodium (45)	Rh 103m		1×10^{-1}
	Rh 105		1×10^{-3}
Rubidium (37)	Rb 86		7×10^{-4}
Ruthenium (44)	Ru 97		4×10^{-3}
	Ru 103		8×10^{-4}
	Ru 105		1×10^{-3}
	Ru 106		1×10^{-4}
Samarium (62)	Sm 153		8×10^{-4}
Scandium (21)	Sc 46		4×10^{-4}
	Sc 47		9×10^{-4}
	Sc 48		3×10^{-4}
Selenium (34)	Se 75		3×10^{-3}
Silicon (14)	Si 31		9×10^{-3}
Silver (47)	Ag 105		1×10^{-3}
	Ag 110m		3×10^{-4}
	Ag 111		4×10^{-4}
Sodium (11)	Na 24		2×10^{-3}
Strontium (38)	Sr 85 *		1×10^{-3}
	Sr 89		1×10^{-4}
	Sr 91		7×10^{-4}
	Sr 92		7×10^{-4}
Sulfur (16)	S 35	9×10^{-8}	6×10^{-4}
Tantalum (73)	Ta 182		4×10^{-4}
Technetium (43)	Tc 96m		1×10^{-1}
	Tc 96		1×10^{-3}
Tellurium (52)	Te 125m		2×10^{-3}
	Te 127m		6×10^{-4}
	Te 127		3×10^{-3}
	Te 129m		3×10^{-4}
	Te 131m		6×10^{-4}
	Te 132		3×10^{-4}
Terbium (65)	Tb 160		4×10^{-4}
Thallium (81)	Tl 200		4×10^{-3}
	Tl 201		3×10^{-3}
	Tl 202		1×10^{-3}
	Tl 204		1×10^{-3}
Thulium (69)	Tm 170		5×10^{-4}
	Tm 171		5×10^{-3}
Tin (50)	Sn 113		9×10^{-4}
	Sn 125		2×10^{-4}
Tungsten (Wolfram) (74).	W 181		4×10^{-3}
	W 187		7×10^{-4}
Vanadium (23)	V 48		3×10^{-4}
Xenon (54)	Xe 131m	4×10^{-6}	
	Xe 133	3×10^{-6}	
	Xe 135	1×10^{-6}	
Ytterbium (70)	Yb 175		1×10^{-3}
Yttrium (39)	Y 90		2×10^{-4}
	Y 91m		3×10^{-2}
	Y 91		3×10^{-4}
	Y 92		6×10^{-4}
	Y 93		3×10^{-4}
Zinc (30)	Zn 65		1×10^{-3}
	Zn 69m		7×10^{-4}
	Zn 69		2×10^{-2}
Zirconium (40)	Zr 95		6×10^{-4}
	Zr 97		2×10^{-4}
Beta and/or gamma emitting byproduct material not listed above with half life less than 3 years.		1×10^{-10}	1×10^{-6}

NOTE 1: Many radioisotopes disintegrate into isotopes which are also radioactive. In expressing the concentrations in Schedule A, the activity stated is that of the parent isotope and takes into account the daughters.

NOTE 2. For purposes of § 30.14 where there is involved a combination of isotopes, the limit for the combination should be derived as follows:

Determine for each isotope in the product the ratio between the concentration present in the product and the exempt concentration established in Schedule A for the specific isotope when not in combination. The sum of such ratios may not exceed "1" (i.e., unity).

Example:

$$\frac{\text{Concentration of Isotope A in Product}}{\text{Exempt concentration of Isotope A}} + \frac{\text{Concentration of Isotope B in Product}}{\text{Exempt concentration of Isotope B}} \leq 1$$

§ 30.71 Schedule B.

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Byproduct material	*Microcuries*
Antimony 122 (Sb 122)	100
Antimony 124 (Sb 124)	10
Antimony 125 (Sb 125)	10
Arsenic 73 (As 73)	100
Arsenic 74 (As 74)	10
Arsenic 76 (As 76)	10
Arsenic 77 (As 77)	100
Barium 131 (Ba 131)	10
** Barium-133 (Ba 133)	10
Barium 140 (Ba 140)	10
Bismuth 210 (Bi 210)	1
Bromine 82 (Br 82)	10
Cadmium 109 (Cd 109)	10
Cadmium 115m (Cd 115m)	10
Cadmium 115 (Cd 115)	100
Calcium 45 (Ca 45)	10
Calcium 47 (Ca 47)	10
Carbon 14 (C 14)	100
Cerium 141 (Ce 141)	100
Cerium 143 (Ce 143)	100
Cerium 144 (Ce 144)	1
Cesium 131 (Cs 131)	1,000
Cesium 134m (Cs 134m)	100
Cesium 134 (Cs 134)	1
Cesium 135 (Cs 135)	10
Cesium 136 (Cs 136)	10
Cesium 137 (Cs 137)	10
Chlorine 36 (Cl 36)	10
Chlorine 38 (Cl 38)	10
Chromium 51 (Cr 51)	1,000
Cobalt 58m (Co 58m)	10
Cobalt 58 (Co 58)	10
Cobalt 60 (Co 60)	1
Copper 64 (Cu 64)	100
Dysprosium 165 (Dy 165)	10
Dysprosium 166 (Dy 166)	100
Erbium 169 (Er 169)	100
Erbium 171 (Er 171)	100
Europium 152 9.2h (Eu 152 9.2h)	100
Europium 152 13 yr (Eu 152 13 yr)	1
Europium 154 (Eu 154)	1
Europium 155 (Eu 155)	10
Fluorine 18 (F 18)	1,000

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[1] Values are given only for those materials normally used as gases.

[2] μCi/gm for solids.

† Amended 38 FR 29314.

* Added 35 FR 3982.

** Added 36 FR 16898.

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Byproduct material	*Microcuries*
Gadolinium 153 (Gd 153)	10
Gadolinium 159 (Gd 159)	100
Gallium 72 (Ga 72)	10
Germanium 71 (Ge 71)	100
Gold 198 (Au 198)	100
Gold 199 (Au 199)	100
Hafnium 181 (Hf 181)	10
Holmium 166 (Ho 166)	100
Hydrogen 3 (H 3)	1,000
Indium 113m (In 113m)	100
Indium 114m (In 114m)	10
Indium 115m (In 115m)	100
Indium 115 (In 115)	10
Iodine 125 (I 125)	1
Iodine 126 (I 126)	1
Iodine 129 (I 129)	0.1
Iodine 131 (I 131)	1
Iodine 132 (I 132)	10
Iodine 133 (I 133)	1
Iodine 134 (I 134)	10
Iodine 135 (I 135)	10
Iridium 192 (Ir 192)	10
Iridium 194 (Ir 194)	100
Iron 55 (Fe 55)	100
Iron 59 (Fe 59)	10
Krypton 85 (Kr 85)	100
Krypton 87 (Kr 87)	10
Lanthanum 140 (La 140)	10
Lutetium 177 (Lu 177)	100
Manganese 52 (Mn 52)	10
Manganese 54 (Mn 54)	10
Manganese 56 (Mn 56)	10
Mercury 197m (Hg 197m)	100
Mercury 197 (Hg 197)	100
Mercury 203 (Hg 203)	10
Molybdenum 99 (Mo 99)	100
Neodymium 147 (Nd 147)	100
Neodymium 149 (Nd 149)	100
Nickel 59 (Ni 59)	100
Nickel 63 (Ni 63)	10
Nickel 65 (Ni 65)	100
Niobium 93m (Nb 93m)	10
Niobium 95 (Nb 95)	10
Niobium 97 (Nb 97)	10
Osmium 185 (Os 185)	10
Osmium 191m (Os 191m)	100
Osmium 191 (Os 191)	100
Osmium 193 (Os 193)	100
Palladium 103 (Pd 103)	100
Palladium 109 (Pd 109)	100
Phosphorus 32 (P 32)	10
Platinum 191 (Pt 191)	100
Platinum 193m (Pt 193m)	100
Platinum 193 (Pt 193)	100
Platinum 197m (Pt 197m)	100
Platinum 197 (Pt 197)	100
Polonium 210 (Po 210)	0.1
Potassium 42 (K 42)	10
Praseodymium 142 (Pr 142)	100
Praseodymium 143 (Pr 143)	100
Promethium 147 (Pm 147)	10
Promethium 149 (Pm 149)	10
Rhenium 186 (Re 186)	100
Rhenium 188 (Re 188)	100
Rhodium 103m (Rh 103m)	100
Rhodium 105 (Rh 105)	100
Rubidium 86 (Rb 86)	10
Rubidium 87 (Rb 87)	10
Ruthenium 97 (Ru 97)	100
Ruthenium 103 (Ru 103)	10
Ruthenium 105 (Ru 105)	10
Ruthenium 106 (Ru 106)	1
Samarium 151 (Sm 151)	10
Samarium 153 (Sm 153)	100
Scandium 46 (Sc 46)	10
Scandium 47 (Sc 47)	100
Scandium 48 (Sc 48)	10
Selenium 75 (Se 75)	10
Silicon 31 (Si 31)	100
Silver 105 (Ag 105)	10
Silver 110m (Ag 110m)	1
Silver 111 (Ag 111)	100

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Byproduct material	*Microcuries*
Sodium 24 (Na 24)	10
Strontium 85 (Sr 85)	10
Strontium 89 (Sr 89)	1
Strontium 90 (Sr 90)	0.1
Strontium 91 (Sr 91)	10
Strontium 92 (Sr 92)	10
Sulphur 35 (S 35)	100
Tantalum 182 (Ta 182)	10
Technetium 96 (Tc 96)	10
Technetium 97m (Tc 97m)	100
Technetium 97 (Tc 97)	100
Technetium 99m (Tc 99m)	100
Technetium 99 (Tc 99)	10
Tellurium 125m (Te 125m)	10
Tellurium 127m (Te 127m)	10
Tellurium 127 (Te 127)	100
Tellurium 129m (Te 129m)	10
Tellurium 129 (Te 129)	100
Tellurium 131m (Te 131m)	10
Tellurium 132 (Te 132)	10
Terbium 160 (Tb 160)	10
Thallium 200 (Tl 200)	100
Thallium 201 (Tl 201)	100
Thallium 202 (Tl 202)	100
Thallium 204 (Tl 204)	10
Thulium 170 (Tm 170)	10
Thulium 171 (Tm 171)	10
Tin 113 (Sn 113)	10
Tin 125 (Sn 125)	10
Tungsten 181 (W 181)	10
Tungsten 185 (W 185)	10
Tungsten 187 (W 187)	100
Vanadium 48 (V 48)	10
Xenon 131m (Xe 131m)	1,000
Xenon 133 (Xe 133)	100
Xenon 135 (Xe 135)	100
Ytterbium 175 (Yb 175)	100
Yttrium 90 (Y 90)	10
Yttrium 91 (Y 91)	10
Yttrium 92 (Y 92)	100
Yttrium 93 (Y 93)	100
Zinc 65 (Zn 65)	10
Zinc 69m (Zn 69m)	100
Zinc 69 (Zn 69)	1,000
Zirconium 93 (Zr 93)	10
Zirconium 95 (Zr 95)	10
Zirconium 97 (Zr 97)	10
Any byproduct material not listed above other than alpha emitting byproduct material	0.1

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